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Cryogenic Orbital Nitrogen Experiment (CONE) - Phase A/B Design Study

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Final Project Report

September 1991

Prepared for:

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Cryogenic On-Orbit Liquid Depot Storage, Acquisition and Transfer Satellite (COLD-SAT) Feasibility Studies Task V Option for a Nitrogen On-Orbit Storage and Supply System Demonstration Termed the Cryogenic Orbital Nitrogen Experiment (CONE) Phase A/B Design Study

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ABSTRACT

Subcritical cryogenic fluid management (CFM) has long been recognized as an enabling technology for future space applications such as Space Transfer Vehicles (for near-earth, lunar and interplanetary missions) and On-Orbit Cryogenic Fuel Depots. Space Station Freedom may also derive benefits from an understanding of CFM. This CFM technology contains many elements which are required to successfully support future system development and mission goals associated with the cost of system operation and reuse. Subcritical liquid storage and supply, however, have never been demonstrated on-orbit. In-space demonstration of this technology using liquid nitrogen (LN2), with a few well defined areas of focus, would provide the confidence level required to implement low-gravity subcritical cryogen use and is a first step towards the more far reaching issue of cryogen transfer and tankage resupply.

The Cryogenic Orbital Nitrogen Experiment (CONE) is a LN2 cryogenic storage and supply system demonstration placed in orbit by the National Space Transportation System (NSTS) Orbiter and operated as an in-bay payload whose objective is to demonstrate critical components and technologies. A conceptual approach has been developed by Martin Marietta and an overview of the CONE program is described which includes the following: (1) a definition of the background and scope of the technology objectives being investigated, (2) a description of the payload design and operation, major features and rationale for the experiments being conducted, and (3) the justification for CONE relating to potential near-term benefits and risk mitigation for future systems. Data and criteria will be provided to correlate in-space performance with analytical and numerical modeling of cryogenic fluid management systems, as well as demonstration data for the mitigation of design risk. CONE results are tailored to provide increased confidence for the use of subcritical cryogen storage and supply for various applications including Space Station Freedom growth options and space propellant storage.

Technical objectives of the CONE mission are highly focused and are divided into priority experiments and demonstrations which are considered a secondary set of cryogenic technologies. Collectively they form the CONE Experiment Set which provide both experimental and demonstration data for future space missions, providing fluid management technology in the following areas of emphasis: 1) cryogenic liquid storage, 2) liquid nitrogen supply, 3) pressurant bottle recharging, 4) active pressure control, and 5) liquid acquisition device performance (expulsion efficiency). Active pressure control is the highest priority of scientific investigation and is the only experiment category of test. All others are demonstrations where the technical objectives tend to be less scientific in nature.

The CONE payload will provide an opportunity to demonstrate the feasibility of combining various methods of integrating pressure control, liquid acquisition, and tank fluid outflow into a subscale experimental tank design that will provide subcritical LN2 storage and outflow characterizations. Controlling tank pressure and supplying single-phase liquid to accomplish transfer and resupply/topoff of tankage is essential to having a space-based operational capability. Using LN2 as the test fluid will provide data acceptable for both oxygen and nitrogen subcritical systems and provides for extrapolation to LH2. In addition, LN2 allows collection of needed cryogenic data without the safety implications associated with liquid hydrogen (LH2) while operating in the more restrictive post-Challenger era of payload safety within the Orbiter cargo bay.

FOREWORD

This report was prepared by the Martin Marietta Corporation, Civil Space & Communications, Denver, Colorado, under Contract NAS3-25063. The contract was administered by the Lewis Research Center of the National Aeronautics and Space Administration, Cleveland, Ohio. The technical period of performance was from February 1989 to July 1991. This report provides the Final Project Report for Task V and conforms to the requirements of DRD-23 of the SOW for both content and format.

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The data in this report are presented in the International System of Units as the primary units and English Units as the secondary units. All calculations and data plots were made in English Units and converted, where possible, to International Units.

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ACRONYMS AND ABBREVIATIONS

ACCEL	Acceleration
ACS	Attitude Control Subsystem
ACT	Auto Configuration Timer
AFD	Aft Flight Deck
AFE	Aeroassist Flight Experiment
AFETR	Air Force Eastern Test Range
AH	Ampere-hour
ALUM	Aluminum
APC	Active Pressure Control
ASAP	As Soon As Possible
ASIC	Asynchronous Interface Controller
ASPC	Attached Shuttle Payload Center
ASSY	Assembly
ATT	Attitude
AVAIL	Available
AVG	Average
BLDG	Building
BOL	Beginning Of Life
BP	Boiling Point
BTU	British Thermal Unit
C	Degrees Centigrade
C&DH	Command And Data Handling
CAT	Category
CB	Circuit Breaker
CCAFS	Cape Canaveral Air Force Station
CCGSE	Customer/Carrier GSE
CDR	Critical Design Review
CFM	Cryogenic Fluid Management
CFME	Cryogenic Fluid Management Experiment
CFMF	Cryogenic Fluid Management Facility
CFTO	Cryogenic Fluid Technology Office
CG	Center Of Gravity
CGSE	Customer GSE
CHX	Compact Heat Exchanger
CMDS	Commands
CNTR	Center
C/O	Checkout
COLD-SAT	Cryogenic On-Orbit Liquid Depot-Storage And Transfer
COMM	Communication
CONE CONN	Cryogenic Orbital Nitrogen Experiment
CONV	Connector
COTS	Converter
CP	Commercial Off-the-shelf
CPCI	Heat Capacity
CPIA	Computer Program Configuration Item
CR	Chemical Propulsion Information Agency
CRT	Concept Review
CTE	Cathode Ray Tube
CTRL	Cryogenic Transfer Experiment
CTU	Control Command And Telemetry Unit
D/C	Duty Cycle, Direct Current
DCE	Data Carrier Equipment
DFRF	Dryden Flight Research Facility
DID	Data Item Description
DMC	Data Management Coordinator
DOT	Department Of Transportation
DRD	Data Requirements Document
DTE	Data Transmission Equipment
E	Exponent, Energy
EA	Engineering Analysis
EDAC	Error Detection & Correction
EGSE	Electrical Ground Support Equipment
E.G.	For Example
ELECT	Electrical
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ENVIRON	Environment
EOL	End Of Life
ESD	Electrostatic Discharge
EST	Estimated
EVE	Experiment Valve Electronics
EX, EXP	Experiment
F	Absorption Fraction, Degrees Fahrenheit
F/D	Fill/Drain
FAB	Fabrication
FEC	Forward Error Correction
FET	Field Effect Transistor
FLT	Flight
FMDM	Flexible Multiplexer Demultiplexer
FME	Flow Meter Electronics
FT	Feet
FTS	Flight Telerobotic Servicer
FOC	Future Operating Condition
FWD	Forward
G'S	Gravity's
GAS	Get-Away-Special
GEN	Generator
GEOSYNC	Geosynchronous
GFP	Government Furnished Property
GG	Gravity Gradient
GH2	Gaseous Hydrogen
GHe	Gaseous Helium
GN2	Gaseous Nitrogen
GND	Ground
GOVT	Government
GPC	General Purpose Computer
GSFC	Goddard Space Flight Center
GSE	Ground Support Equipment

ACRONYMS AND ABBREVIATIONS

H	Hydrogen
HEX	Hexadecimal
HH-G	Hitchhiker-G
HH-M	Hitchhiker-M
H2	Hydrogen
H&S	Health And Safety
HT	Heat
HX	Heat Exchanger
HTRS	Heaters
HW	Hardware
HZ	Hertz
I	Inertia
I/O	Input/Output
I/V	Current/Voltage
ID	Identify
IF,I/F	Interface
IN	Inches
IOC	Initial Operating Condition
IPD	Information Processing Division
IRAD	Internal Research & Development
IRIG-B	Interrange Instrumentation Group B
IRU	Inertial Reference Unit
ISTV	Initial Space Transfer Vehicle
JSC	Johnson Space Center
J-T	Joule-Thomsen
K	Thousand, Kelvin
KBPS	Kilobits Per Second
KSC	Kennedy Space Center
KWHR	Kilowatt Hour
L	Liquid, Liter
L/D	Length/Diameter
LAD	Liquid Acquisition Device
LBF	Pounds Force
LBM	Pounds Mass
LBS	Pound
LC39	Launch Complex 39 (at KSC)
LCC	Launch Commit Criteria, Life Cycle Cost, Launch Control Center
LeRC	Lewis Research Center
LH2	Liquid Hydrogen
LN2	Liquid Nitrogen
LO2	Liquid Oxygen
LOC	Lines Of Code
LOHM	Measure Of Fluid Resistance
LRGSE	Low Rate GSE
LSA	Launch Services Agreement
LTV	Lunar Transfer Vehicle
LV	Launch Vehicle
LVPD	Liquid Vapor Position Detector
M	Mass, Meter
M/V	Mass/Volume
MAX	Maximum
MB	Megabite
MCC-H	Mission Control Center (at Houston)
MDB	Multiplex Data Bus
MDM	Multiplexer/Demultiplexer
MET	Mission Elapsed Time
MGMT	Management
MGR	Manager
MGSE	Mechanical GSE
MIL-STD	Military Standard
MISC	Miscellaneous
MIT	Massachusetts Institute Of Technology
MITAS	Martin Interactive Thermal Analysis System
MLI	Multi-layer Insulation
MMAG	Martin Marietta Aerospace Group
MMCAP	Martin Marietta Cryogenic Analysis Prgm
MMI	Man Machine Interface
MMS	Multi Mission Spacecraft
MMSE	Multi Mission Support Equipment
MODS	Modifications
MPS	Mission Planning System
MPESS	Mission Peculiar Equipment Support Structure
MPL	Maximum Predicted Level
MRO	Memory Readout
MTG	Mounting
MUX	Multiplexer
N	Newton
NASA	National Aeronautics and Space Administration
NASCO	NASA Communication Lines
NC	Normally Closed
NCC	Network Control Center
NEC	National Electrical Code
NGT	NASA Ground Terminal
NICD	Nickel Cadmium
NIST	National Institute Of Standards & Tech
NMI	Nautical Miles
NO	Normally Open
NSP	Network Signal Processor
NSTS	National Space Transportation System
OAET	Office of Aeronautics and Exploration Technology
OBC	On-Board Computer
O&C	Operations And Checkout
OC	Operations Controller
OD	Operations Director
OHX	Outflow Heat Exchanger
OIT	Orbiter Interface Test
OPS	Operations
OPT	Option
ORS	Orbital Resupply System
OSCRS	Orbital Spacecraft Consumable Resupply System
OSCF	Operations Support Computing Facility
OTV	Orbital Transfer Vehicle

ACRONYMS AND ABBREVIATIONS

P	Pressure
ΔP	Change In Pressure
P-V-T	Pressure-Volume-Temperature
P/L	Payload
P/N	Part Number
PCM	Pulse Code Modulation
PCR	Payload Changeout Room
PDI	Payload Data Interleaver
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PETS	Payload Environmental Transportation System
PGHM	Payload Ground Handling Mechanism
PHR	Payload Hazard Report
PHSF	Payload Hazardous Servicing Facility
PI	Principal Investigator
PLAYBK	Playback
PLCS	Places
PME	Propulsion Module Electronics
POCC	Payload Operations Control Center
POS	Position
PPF	Payload Processing Facility
PPM	Parts Per Million
PRCS	Primary Reaction Control System
PRD	Payload Requirements Document
PROC	Processor
PROM	Programmable Read-only Memory
PRR	Preliminary Requirements Review
PSP	Payload Signal Processor
PV	Pressure Vessel
Q	Heat Flux, Heat Rate
R	Degrees Rankine, Probability Of Success (Reliability)
RAM	Random Access Memory
RC,RCVR	Receiver Tank
RCTU	Remote Command & Telemetry Unit
REC	Recorder
REQD	Required
REQT	Requirement
ROM	Read Only Memory
RSS	Rotating Service Structure
RTD	Resistance Temperature Device
RTN	Return
S/C	Spacecraft
S/S	Subsystem
S/W	Software
SAMS	Space Acceleration Measurement System
SAT	Saturated
SBSSF	Space Based Space Station Freedom
SCA	Shuttle Carrier Aircraft
SDIO	Space Defense Initiatives Office
SDR	Systems Design Review
SE	Support Equipment
SEN	Sensor
SEP	Separate
SEQ	Sequence
SFMD	Storable Fluid Management Demonstration
SHOOT	Super Fluid Helium On-orbit Transfer
SINDA	System Improved Numeric Differencing Analyzer
SLF	Shuttle Landing Facility
SM	Submodule, Safety Margin
SMCH	Standard Mixed Harness Cable
SOW	Statement Of Work
SPECS	Specifications
SPS	Samples Per Second
SSF	Space Station Freedom
SSP	Standard Switch Panel
STA	Station
STD	Standard
STE	System Test Equipment
STS	Space Transportation System
STV	Space Transfer Vehicle
T	Temperature
TA	Test Article
TBD	To Be Determined
T2C2	Telemetry, Tracking, Command & Control
TC	Temperature Coefficient
TCS	Thermal Control S/S
TDRSS	Tracking & Data Relay Satellite System
TIM	Technical Interchange Meeting
TK	Tank
TLM	Telemetry
TRASYS	Thermal Radiation Analysis System
TSS	Tether Satellite System
TTL	Transistor-Transistor Logic
TVS	Thermodynamic Vent System
U/L	Uplink
UTC	Universal Time Constant
V	Volume, Vapor
VCS	Vapor Cooled Shield
VDA	Valve Drive Amplifier
VJ	Vacuum Jacket
VLV	Valve
VPF	Vertical Processing Facility
VRCS	Vernier Reaction Control System
W	Weight,Watts,Rate
W/	With
WBS	Work Breakdown Structure
WK	Work
WSGT	Whitesands Ground Terminal
X-POP	X Axis Perpendicular To The Orbit Plane
X-SI	X Axis Solar Inertial
Z-LV	Z Axis Local Vertical
Z-SI	Z Axis Solar Inertial

ACRONYMS AND ABBREVIATIONS

α/ε	Alpha/Epsilon - Solar Absorptivity/Emissivity
η	Efficiency
σ	Stefan-Boltzmann Constant, Surface Tension
μ	Viscosity
μDACS	MicroDACS
ε	Emissivity
ρ	Density
ϕ	Phase
Δ	Change
γ	Gamma Rays

1.0 EXECUTIVE SUMMARY

The Cryogenic Orbital Nitrogen Experiment (CONE) is a liquid nitrogen (LN2) cryogenic storage and supply system demonstration placed in orbit by the National Space Transportation System (NSTS) Orbiter and operated as an in-bay payload whose objective is to provide cryogenic storage system demonstrations focusing on high priority technology for efficient, effective and reliable management of cryogenic fluids in the reduced gravity space environment. Fundamental data required for the understanding and design of subcritical cryogenic systems is lacking; the CONE program will provide a start towards the development of this necessary database and provide preliminary low-g data of subcritical cryogenic storage, pressure control and tank outflow process capabilities. Subcritical cryogenic fluid management (CFM) has long been recognized as an enabling technology for future space applications such as Space Transfer Vehicles (for near-earth, lunar and interplanetary missions) and On-Orbit Cryogenic Fuel Depots. Space Station Freedom will also derive benefits from an understanding of CFM, as well as growth Orbiters and other manned presence in space programs requiring efficient storage of propellents, process consumables and life support gases.

This CFM technology contains many elements which are required to successfully support future system development and mission goals associated with the reduced cost of system operation and reuse. Extending the useful life of these systems can be realized by periodic resupply. Before cryogens can be transferred from tank-to-tank, the capability to properly store, maintain and outflow in the low-g environment must be demonstrated. Subcritical liquid storage, supply, outflow, transfer, and resupply, however, have never been demonstrated on-orbit. In-space demonstration of this technology using LN2, with a few well defined areas of focus, would provide the confidence level required to implement low-gravity subcritical cryogen use. Various mission scenarios are totally dependent on fluid transfer and resupply for mission success and have provided the impetus to pursue this first step in CFM technology development in a timely manner to support the design efforts and help mitigate risk associated with the evolution of these programs.

The technical requirements of the CONE payload have been defined, a conceptual approach has been developed along with a more refined system design and an overview of the CONE program is described which includes the following: (1) a definition of the background and scope of the technology objectives being investigated, (2) a description of the payload design and operation, major features and rationale for the experiments being conducted, and (3) the justification for CONE relating to potential near-term benefits and risk mitigation for future systems.

1.1 Introduction

The CONE payload (shown in Figure 1.1-1) is an integrated NSTS experimental payload that uses a Hitchhiker - M Carrier for mounting and Orbiter services interfacing. It is designed to provide focused investigations of the fluid thermophysics of subcritical cryogens in a low-gravity space environment and to provide data and criteria to demonstrate in-space performance. CONE evolved from the Cryogenic On-Orbit Liquid Depot Storage, Acquisition and Transfer Satellite (COLD-SAT) program which investigated cryogenic fluid management technologies using an experimental spacecraft launched from an expendable launch vehicle. COLD-SAT was designed, using LH2, to investigate the systems and technologies required for efficient, effective and reliable management of cryogenic fluid in the reduced gravity space environment. The cost and risk associated with the COLD-SAT approach suggested that a small subscaled precursor experiment would be appropriate to provide needed up-front data and performance information that would also be useful for current STV and SSF applications. After the Challenger accident, LH2 payloads [such as Centaur and the Cryogenic Fluid Management Facility (CFMF)] were excluded from the bay. CONE provided the logical means to economically and with acceptable risk to the NSTS (using LN2 as the test fluid) initiate the required CFM technology program.

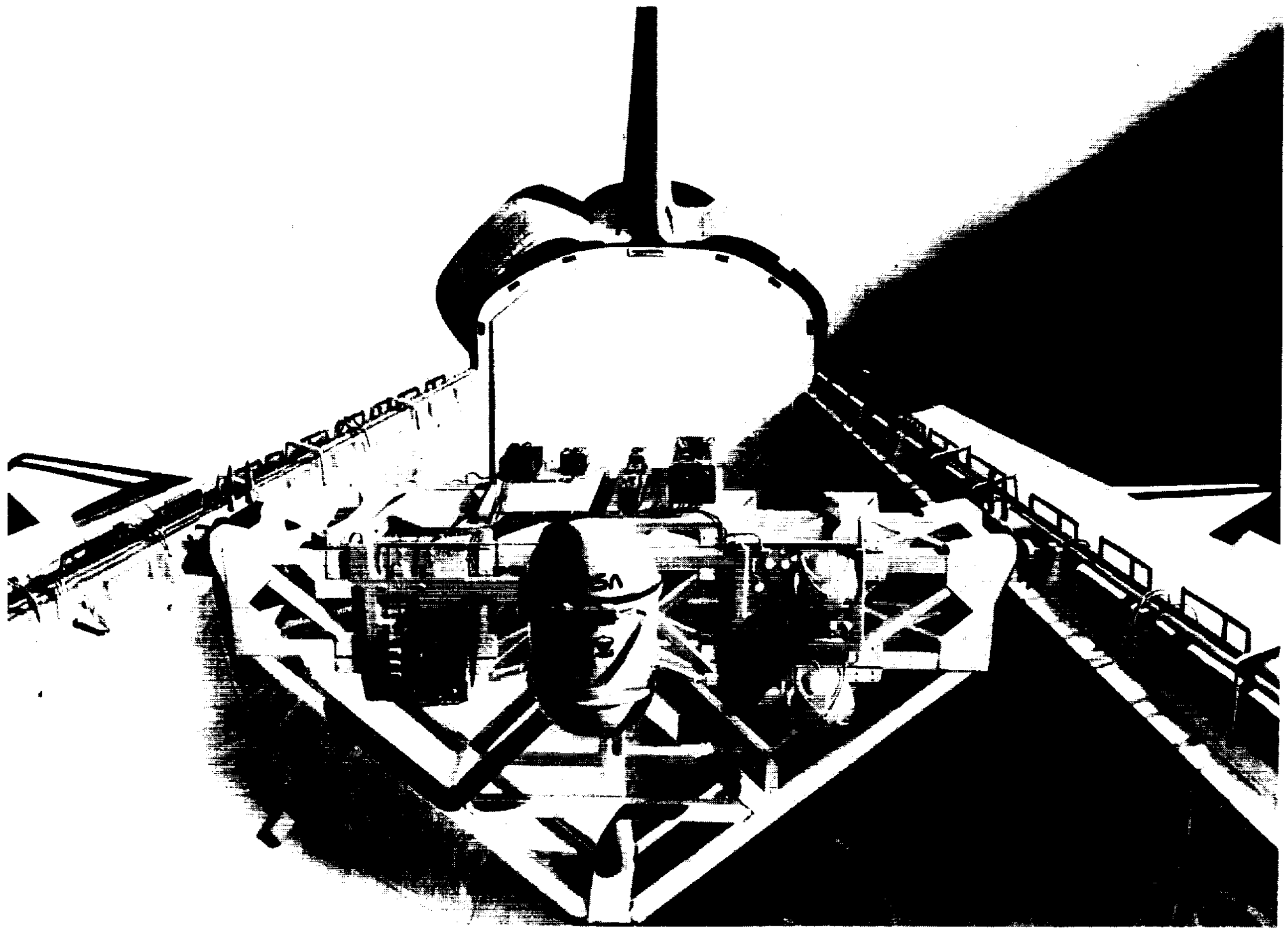


Figure 1.1-1 CONE Payload Configuration on the Hitchhiker- M Carrier

1.2 Low-Gravity Cryogenic Fluid Management Technologies

Subcritical cryogenic fluid management technology for cryogens stored at low pressure contains many elements which are required to successfully support future space system development and mission goals associated with the cost of system operation, safety and reuse. The most basic elements of the technology are an understanding of the storage, pressure control and tank outflow requirements for subcritical cryogenic fluids.

Existing cryogen storage and supply systems utilize well characterized supercritical techniques that are weight intensive due to the high pressure required to assure that a single phase is maintained in the tank. Substantial weight savings can be realized by low pressure subcritical storage where two phase fluid is stored and liquid only is provided to a user by a surface tension liquid acquisition device (LAD). CONE on-orbit testing in the areas of liquid storage using both active and passive techniques to control tank pressure, along with the assessment of supplying vapor-free LN2 from the tank by use of a LAD, is the first step towards the implementation of future in-space subcritical cryogen use.

Over the years, a three step approach to cryogenic fluid management technologies has been defined starting with individual component and hardware development, progressing to subsystem element ground based testing and finally to in-space experimentation. All result in the establishment of a cryo data base and to the development of refined analytical models which make use of the available data for validation and correlation purposes. CONE is the first precursor experiment to implement a cost effect, subscale on-orbit test approach focused on the near term needs of the space community.

1.3 CONE Experiment Set Overview

The experimentation and demonstration test categories comprise the primary and secondary technical mission objectives. Tests in each category include low-g fluid and thermal process investigations, demonstrations of performance capabilities, as well as technology evaluations to achieve an overall test mix that provides for a maximized technological return of data over the duration of the mission. Figure 1.3-1 shows these objectives and the subelements of each. A brief listing of individual experiment objectives are as follows:

Tank Active Pressure Control - Investigating the phenomena associated with the control of cryogenic storage tank pressure using an axial jet induced mixer coupled with a compact thermodynamic vent system (TVS) heat exchanger is the specific objective of this test series. A parametric assessment will be conducted to investigate the effects of tank heat flux, mixer flow rate, compact heat exchanger flow rate, tank liquid level and the acceleration environment on: 1) thermal stratification, 2) thermal destratification by mixing and, 3) tank pressure reduction during heat exchanger operation. Results will be compared with analytical predictions to provide partial verification of of the models which describe the physical processes involved.

The remaining technical objectives are lower priority system demonstrations consisting of the following:

Cryogenic Liquid Storage - The capability of a passive TVS to maintain a nearly constant tank pressure at various fill levels will be determined by tests conducted at background acceleration levels. The TVS will be either wall mounted or attached to the LAD. Heat flux will be varied to simulate thermal performance typical for both vacuum jacketed and foam/MLI insulated cryogen storage systems so that data results can be compared with analytical predictions for these different heat flux cases.

Liquid Nitrogen Supply - The specific objective of this test series is to demonstrate the capability to supply subcooled vapor-free LN2 to a simulated user by expelling tank liquid using a total communication capillary type fine mesh screen LAD. Expulsion will be provided by gaseous nitrogen (GN2), stored in high pressure bottles, and regulated to 207 kN/m^2 (30 psia) prior to introduction to the LN2 storage tank. Pressurant consumption rates will be determined and compared to analytical predictions at a high and a low fill level in the LN2 storage tank, for two values of liquid subcooling, and for two different expulsion rates. Tank outflows will incorporate the assessment of advanced technology mass flow metering instrumentation.

Pressurant Bottle Recharging - This demonstration will assess the capability to resupply a depleted gaseous nitrogen pressurant bottle by injecting a metered quantity of LN2. A depleted pressurant bottle will be evacuated to space and then chilled to a predetermined target temperature. The chilldown charge will be evacuated to space and will be followed by the injection of a metered quantity of LN2. This charge amount will be allowed to self-pressurize using ambient environmental heating. Target temperature, charge mass, and final bottle pressure will be determined and compared to analytical predictions.

LAD Performance - Investigations of the capability of the LN2 storage tank LAD to provide vapor-free liquid to the point of breakdown will determine the expulsion efficiency for the device and will provide a single data point on the LAD retention capability for comparison to analytical models describing the LAD performance .

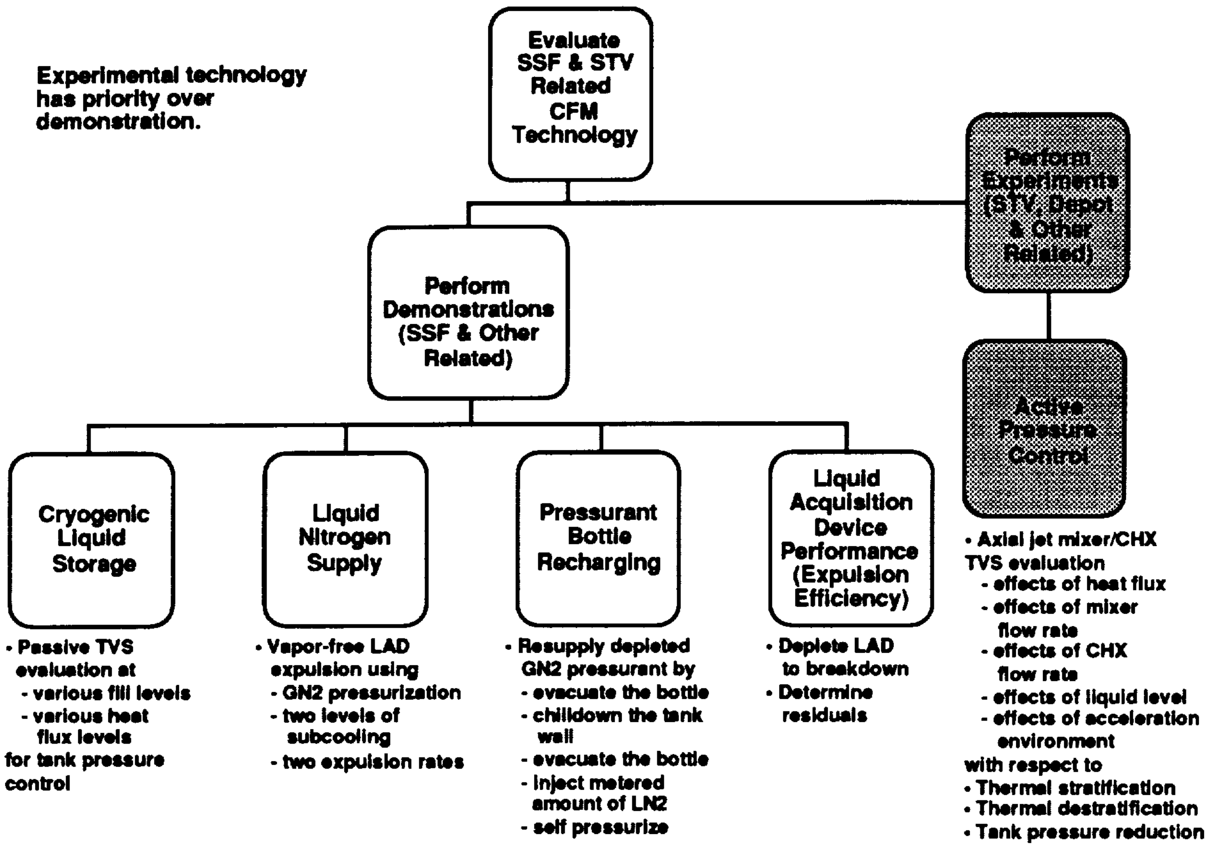


Figure 1.3-1 CONE Experiment Science Technical Objectives

1.4 Payload Experiment Subsystem Description

The CONE Experiment Subsystem is composed of the following three major elements: liquid nitrogen storage and supply tank, LN2 storage tank valve module, and GN2 pressurization & LN2 bottle recharge module. Instrumentation is included in each element. Figure 1.4-1 shows a schematic of the inter-relationship of the experiment subsystem elements.

Definition of Major Subsystem Elements

LN2 Storage Tank. This tank has a pressure vessel of 0.226 m^3 (8 ft^3) capable of holding 171 kg (375 lbs) of LN2 at 95% full and is completely contained by a vacuum jacket (VJ). To maintain a shape relationship to typical space based transfer vehicle tankage and in order to provide for a stable fluid interface, a cylindrical tank shape was selected. The overall tank VJ has a diameter of 68.6 cm (27 in) and a length of 121.9 cm (48 in) to provide the largest size tank that could be mounted to the front face of the Hitchhiker-M carrier. The pressure vessel (PV) has a diameter of 58.4 cm (23 in) and contains a total communication LAD with an outlet at the top of the tank. A vent/pressurization penetration which feeds directly into the tank via a diffuser is located at the top end so that contact with ullage is maintained for both horizontal and vertical positions of the tank. Pressurant is introduced into the tank by this line. An axial jet spray system is provided through which liquid can be introduced from a mixer pump to provide mixing of the bulk fluid. Mixer pump fluid is passed through a compact heat exchanger (CHX) where energy can be removed from the tank to actively control or reduce tank

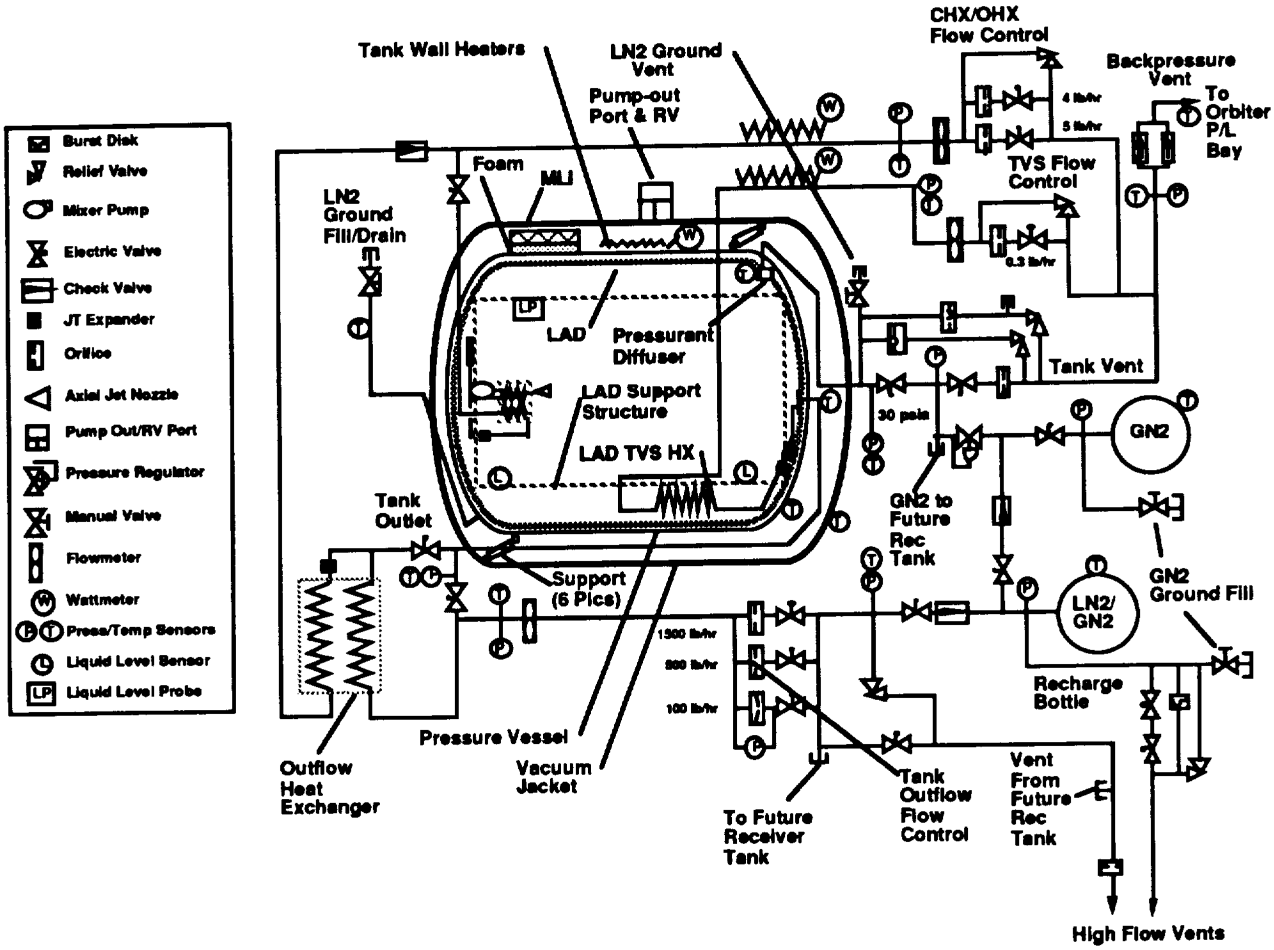


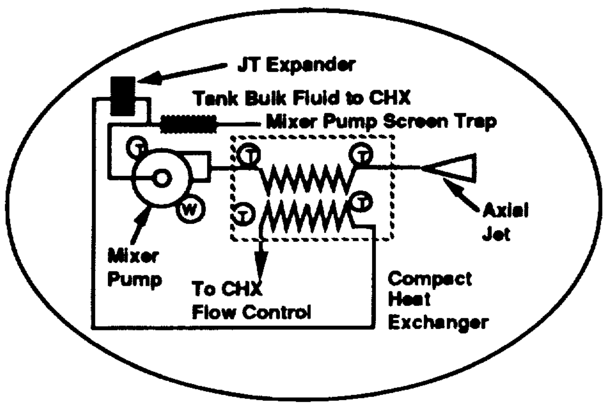
Figure 1.4-1 Experiment Subsystem Simplified Schematic

pressure. An internal thermodynamic vent system (TVS) heat exchanger (HX) routed on the LAD is provided to cool the bulk fluid and passively control tank pressure. Thermal control heaters uniformly cover the pressure vessel and are used to vary the heat flux for pressure control and stratification experiments. A layer of foam insulation covers the heater blanket to provide protection against a loss of annular vacuum and limit the venting potential for this off-nominal case. Multi-layer insulation (MLI) is located over the foam insulation for nominal on-orbit control of tank heat leak. All plumbing penetrations from the PV are routed internal to the VJ and exit at the girth ring area. An outlet heat exchanger (OHX) mounted to the VJ girth allows for subcooling of the tank outflow. The PV connects to the VJ with a strap suspension system. Figure 1.4-2 shows the details of the mixer/CHX and the tank outlet.

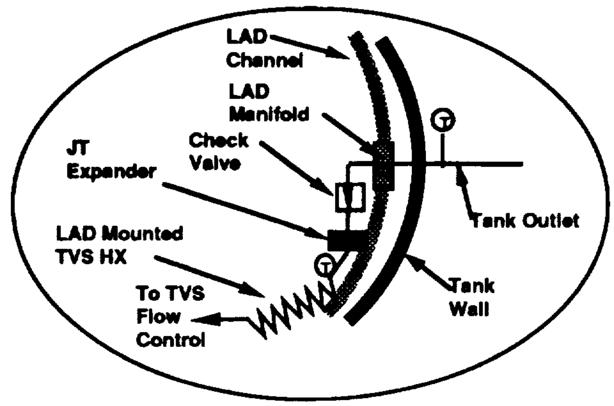
<u>LN2 Storage Tank Valve Module</u>. All components that interface with the back pressure vent and provide LN2 storage tank pressure relief or isolation for TVS, CHX, OHX flow rate control and tank venting/pressure introduction, as well as instrumentation for flow monitoring are accommodated by this module. Redundant mechanical burst disk/relief assemblies provide overpressure protection for the tank at 345 kN/m ^{2} (50 psia).

<u>GN2 Pressurization & LN2 Bottle Recharge Module</u>. Components associated with pressurant storage, ground servicing, regulation and distribution, as well as the LN2 storage tank outflow line and the LN2 recharge bottle are assembled into a self contained module. Pressurant storage is provided by

two spherical 35.6 cm (14 in) diameter 0.023 m^3 (0.83 ft^3) tanks pressurized to 20670 kN/m^2 (3000 psia) on the ground prior to flight. Each tank stores 5 kg (11 lbs) of GN2. Ground GN2 servicing interfaces and manual valving for loading GN2 into the pressurant bottles are incorporated. The outflow line from the LN2 storage tank with flow control for 45, 227 and 682 kg/hr (100, 500 and 1500 lb/hr), respectively is provided, as is the supply line to the LN2 recharge bottle. Interfaces to the high flow in-space vents are accommodated by this module. A fixed regulator controls delivered pressurant to 207 kN/m^2 (30 psia) for introduction into the LN2 storage tank.



Tank Mixer Pump & CHX Detail



Tank Outlet Detail

Figure 1.4-2 LN2 Storage Tank Internal Details

Instrumentation. Instrumentation required to monitor the experimental and demonstration categories of test consists of temperature, pressure, flowrate, valve position, liquid/vapor detection, and fluid quality discrimination measurements required to monitor specific data collection needs. Table 1.4-1 provides a summary of these devices.

Table 1.4-1 Experiment Instrumentation Summary

Temperature	54
Pressure	13
Flowrate	3
Liquid Level	6
Events	17
Acceleration	3
Power	3

1.5 Payload Support Subsystem Description

The support subsystems augment the experiment subsystem in the accomplishment of the mission science and operational objectives. Together they comprise the payload flight element of the CONE System. The following provides a brief description of the support subsystems which are functionally depicted with the experiment subsystem in Figure 1.5-1. Figure 1.5-2 views the CONE mounted to the HH-M carrier.

Major Support Subsystem Elements

Structures Subsystem. This subsystem provides the structural mounting for all support and experiment subsystem elements to the HH-M carrier, as well as attachment of CONE subsystem elements to one another. The supports and struts connecting the LN2 storage tank to the HH-M truss comprise the major elements of this subsystem. All component mounting brackets, clamps,base plates and attachment structure complete the definition of this subsystem.

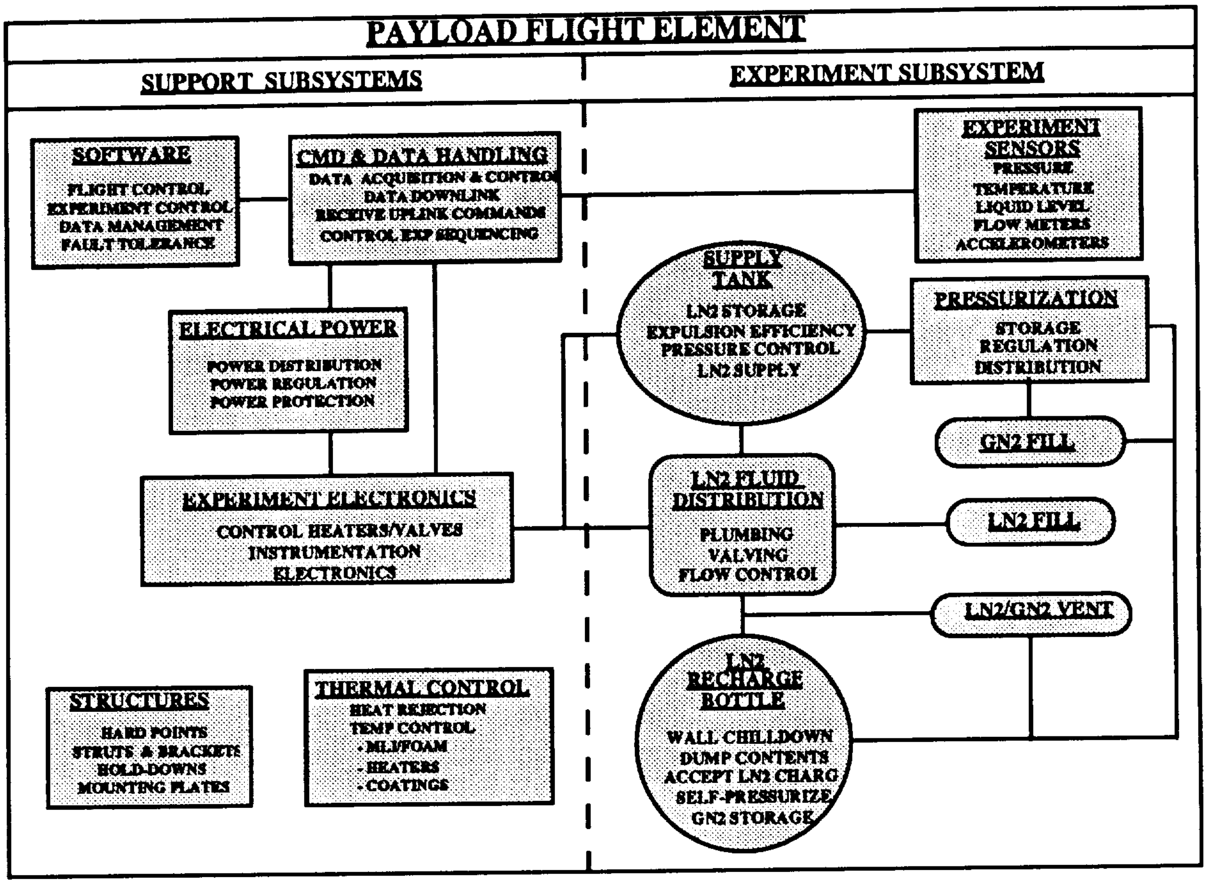


Figure 1.5-1 Payload Flight Element Subsystem Functional Block Diagram

Electrical Power Subsystem (EPS). The EPS controls, conditions, distributes, monitors and provides power bus isolation and protection. A Power Distribution Unit (PDU) provides protection, control and distribution of 28 vdc electrical power from the HH-M avionics unit to electrical elements on the payload. The PDU also provides power to the experiment mixer pump, heaters and valves via the Experiment Valve Electronics (EVE) unit.

Command & Data Handling (C&DH) Subsystem. The C&DH provides for formatting and transmission of housekeeping and experiment data and the capability for the decoding and distribution of commands to operate the payload during the mission. The C&DH also provides for the transmission of data downlink and the acceptance of ground command uplink via standard Orbiter communication links that interface with the HH-M avionics unit. Off-the shelf hardware is utilized and contains elements that accomplish control and monitoring of the sensors, valves, and other components of the experiment subsystem. Control of the experiment sequencing functions is handled by the on-board computer (OBC). Communications between the C&DH and the other subsystems is via a multiplex data bus.

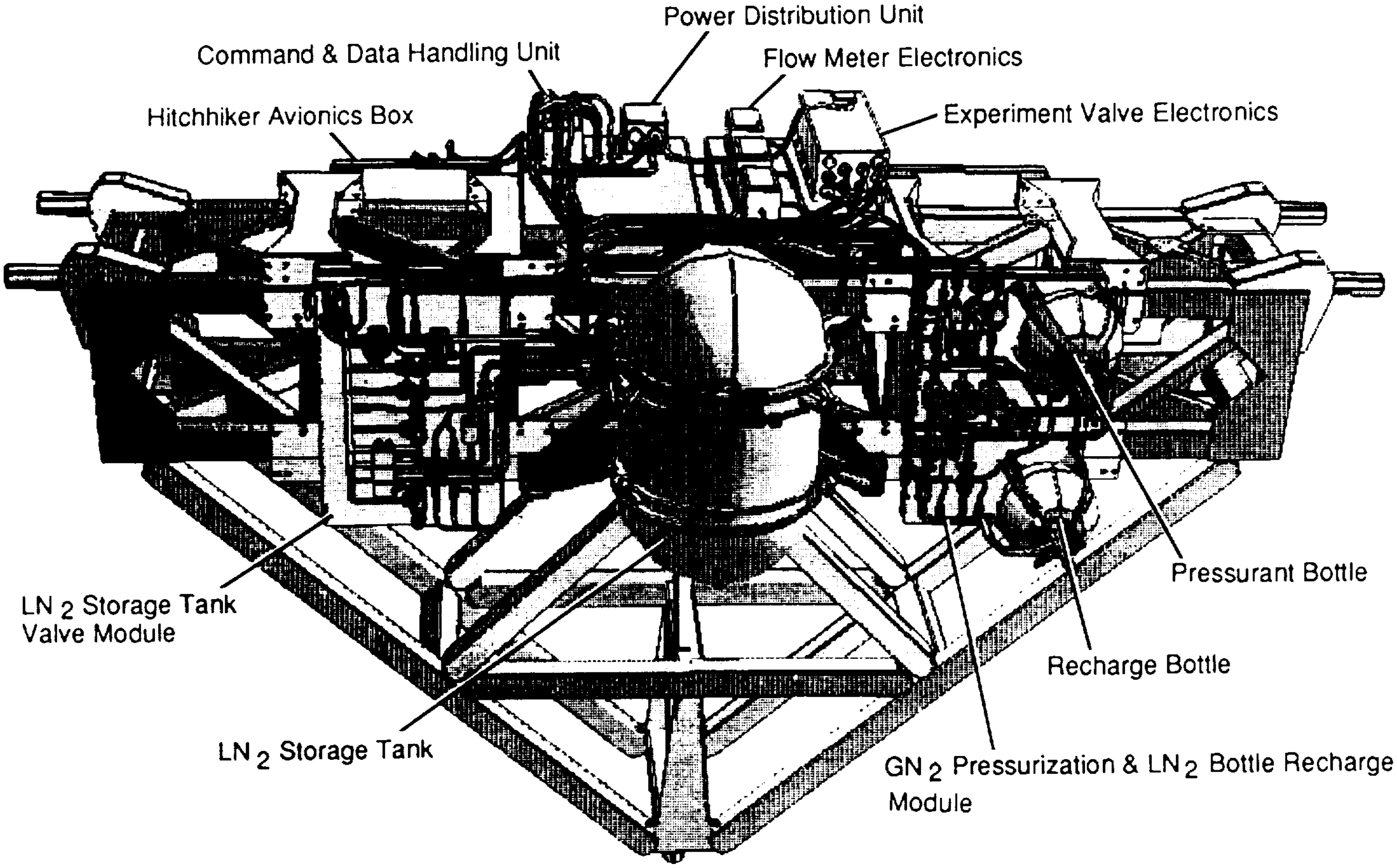


Figure 1.5-2 CONE Payload Element Definition

Experiment Electronics Subsystem.This subsystem contains the experiment valve electronics (EVE) unit which controls the application of power commands to heaters and valves in the experiment subsystem. It provides the interface between the C&DH and the components that have to be controlled in the experiment subsystem. Also all instrumentation requiring unique electronics for signal conditioning or power regulation have these units located in this subsystem.

Thermal Control Subsystem (TCS). The TCS consists of thermal coatings, insulation, sensors, heaters and associated thermostats, and radiative surface configurations required to control and monitor the thermal environment to within proper operating ranges for all payload hardware. This design approach provides passive thermal balance of the entire payload using the above specified techniques, as appropriate.

Vehicle Flight Software. Vehicle flight software consists of computer programing which will be resident in the OBC that will perform operations and computations in support of experiment and health monitoring functions, manage data collection, control the telemetry and experiment subsystem operation, and provide necessary system management and fault protection function.

Table 1.5-1 lists the general top-level characteristics of the CONE payload.

1.6 Ground Segment and Interfaces Description

The CONE Ground Segment provides for associated pre-flight, in-flight, and post-flight support functions. Figure 1.6-1 provides a definition of the CONE System and the functional interfaces required to operate the system . Internal payload and ground support equipment interfaces (both mechanical and electrical) are also shown.

Table 1.5-1 CONE Characteristics

Size:	Entire front face of the HH-M carrier with avionics mounted on two standard plates
Carrier:	Hitchhiker-M
Dry Weight:	393 kg (865 lb)
Consumables:	171 kg (375 lb) LN2 and 10 kg (22 lb) GN2
Launch Weight:	574 kg (1262 lb)
Launch Condition:	Powered down with LN2 storage tank TVS operating
Mission Duration:	Six days nominal
Orbital Attitude:	Random - with fixed periods of low perturbation at maximum Orbiter drag acceleration
Power Consumption:	250 watts average - 500 watts maximum
Operations Approach:	On-board experiment sequencing with ground POCC monitoring and contingency control intervention

<u>Major Ground Segment Elements</u>

<u>Mechanical Ground Support Equipment (MGSE)</u>. The MGSE provides ground servicing, handling support, transportation support, and maintenance functions for the payload. The major MGSE structural hardware items include a protective cover for transport, handling and rotation dolly, handling/lifting slings, holding fixtures and installation tools. Support equipment for the experiment subsystem includes a LN2 servicing/deservicing system, GN2 pressurant servicing system, experiment system leak check kits, fluid support equipment and miscellaneous calibration equipment.

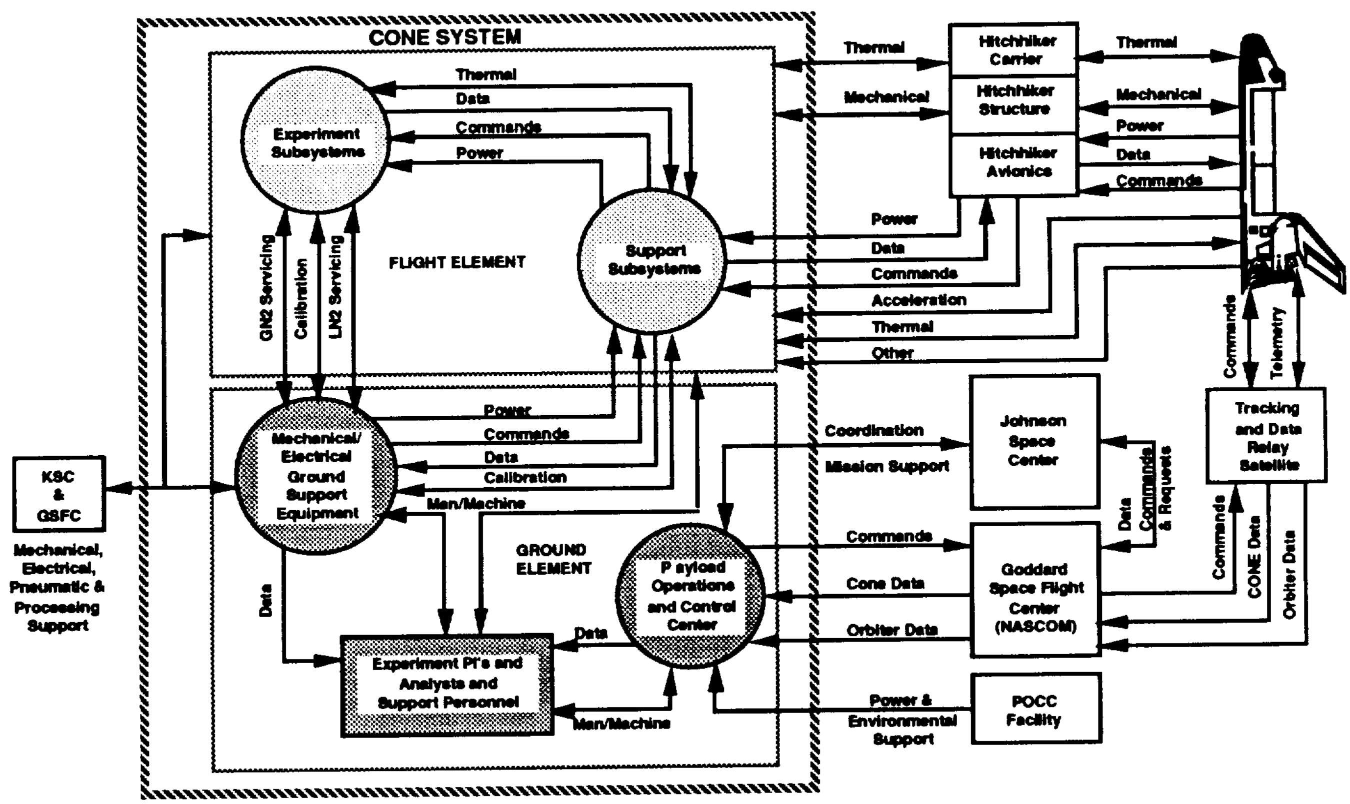


Figure 1.6-1 CONE Internal and External Functional Interfaces

Electrical Ground Support Equipment (EGSE). The EGSE provides command, control, calibration, simulation, ground 28 Vdc power to the payload, and data management of the support and experiment subsystems during ground test and checkout operations. A major portion of the EGSE hardware is the payload C&DH support equipment comprised of a mission sequence and command generation system, EEPROM programmer, power supplies, monitoring system, display equipment and printer. In addition, a power distribution system, payload electrical power subsystem support equipment and electronics integration test set are provided.

Payload Operations Control Center (POCC). A POCC located at NASA Goddard Space Flight Center provides in-flight command, control and management of flight data (both realtime and recorded) for CONE. Operations software is included in the POCC. The POCC includes a router, telemetry preprocessor, data management work stations, mission planning and scheduling work stations, and personal computers for experiment commanding, monitoring and data processing.

1.7 Mission Description

The CONE on-orbit mission was developed so that the experiments and demonstrations could be accomplished on a nominal seven day Orbiter mission. Figure 1.7-1 shows the mission timeline that was assembled to accommodate all of the tests within this time constraint while allowing for periods of system operations holds to provide for coordination with the crew and other operations that may impact the flow of desired CONE operations. Tests are arranged into six groups with the first three occurring at the high fill level for LN2 in the storage tank and the last three at a lower level resulting from the first expulsion (supply test). Active pressure control (APC) assessments comprise the majority of the mission events. The ordering of events had to accommodate crew availability to support orbiter operations for attitude and thruster firings for fluid positioning/settling. Two stratification tests desire periods of fluid quiescence and settling using Orbiter drag to orient LN2 in the storage tank. These operations are best accomplished during crew sleep periods and do not require crew involvement. All LN2 and GN2 will be depleted and expelled to space during a nominal mission; the system will return without concern for tank residuals.

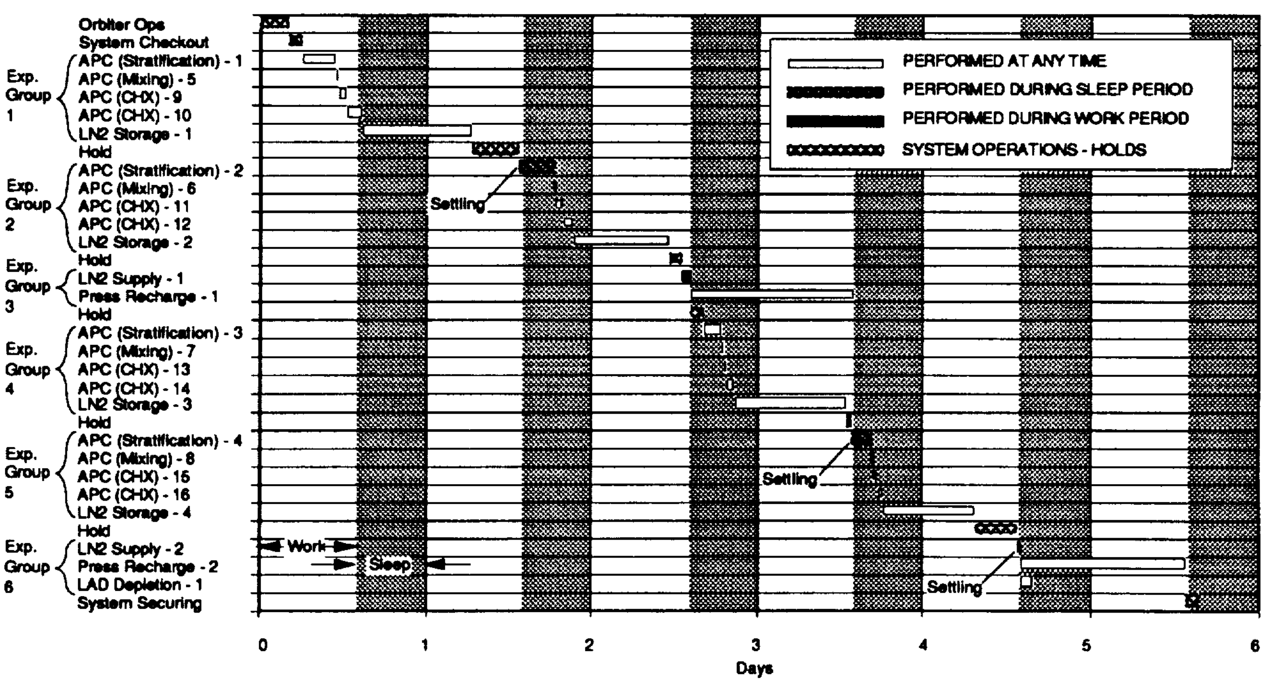


Figure 1.7-1 CONE Experiment/Demonstration Science On-Orbit Timeline

1.8 Program Status

The CONE Phase A/B Design Study was concluded in July 1991. It is planned to be followed with a phase C/D program that will take the design approach through finalized design, fabrication, subsystem integration, test, ground processing, NSTS integration, launch, on-orbit mission operations, and return and deintegration of the payload. Post mission data analysis and mission results reporting will also be supported. Current planning for this program (subject to continued NASA supporting budget activities) begins the effort in 1993 with a flight in mid 1997 timeframe. A projected program contract cost of $20-35M is envisioned.

A lack of funding prevented the incorporation of fluid transfer into the CONE technology. This would have resulted in the addition of a receiver tank to the CONE configuration and impacting the CONE approach to accommodate this modification. Implementing such an change has been deferred to the beginning of the phase C/D effort where an early 3-4 month assessment of this addition would be made before proceeding with the rest of the program.

1.9 Technology Issues

Technology issues associated with accomplishing CONE technical objectives relating to the design approach for the experiment and support subsystems have only identified two items that require development to the extent of requiring new designs that are at or near the state-of-the-art of technology. These include the LN2 mixer pump and the LN2 storage tank continuous liquid level probe. The remainder of the design utilizes existing hardware designs or modifications to existing designs.

1.10 Conclusions and Recommendations

The following major conclusions and recommendations were compiled during the course of the CONE design study effort:

- We have selected the Hitchhiker-M as the most cost effective carrier for the CONE payload in the defined weight class of 545 kg (1200 lbs) with margin included. This choice also took into account the carrier services and interfaces to the needed Orbiter systems.
- Our selected avionics approach utilizes derivatives of existing qualified and flight proven C&DH systems that are going to be used on various missions in the next two years.
- A modularized approach for the experiment subsystem consists of the LN2 storage tank and two component/valve modules. The avionics subsystem also has been packaged for effectiveness, proximity and minimizing cable harness lengths.
- Selection of a suitable supply tank size, which established the mission LN2 budget, resulted in a final size of 0.266 m^3 (8 ft^3). While this size fluctuated over the study and was driven to a 58.4 cm (23 in) diameter size due to scaling studies, payload carrier loading constraints and time constraints imposed by passive TVS operation. A vacuum jacket was baselined for safe LN2 servicing and containment on the ground. Scaling of experiment design were based on:
  - tank size / experiment weight
  - shape scaled to outdated STV

  Note: The drivers for scaling have to be defined by NASA LeRC for follow-on efforts

- An on-orbit test approach was baselined that accommodated all defined technical objectives.
- The mission duration is 5-6 days and should be able to be accommodated on a standard Orbiter mission.

Several recommendations for changes to our baseline configuration call for additional effort beyond the work performed from our design study activities. These resulted from a request to propose incorporating fluid transfer as a technical objective and include:

• Provisions for space and weight allocations for the receiver tank and associated components in the mounting and placement of system elements on the HH-M carrier.
• Provisions in the design for the addition of these extra system elements.
• Impacts of such an addition have not been made and could have a major effect on the LN2 storage tank size, if additional LN2 is needed, as well as additional GN2 pressurant.
• Integration of fluid transfer will impact the defined experiment set, mission timeline and LN2 budget allocation for each test.

While cryogen transfer and resupply to a receiver tank is currently not a part of the technical objectives, we believe that such a requirement could be accommodated into CONE and accomplished in a single Orbiter flight.

During the performance of the design study there was no formal NASA Headquarters approval of a NASA LeRC submitted Form 1628 - Request for Flight Assignment. As a result, necessary interfacing with GSFC, JSC and KSC only took place on an informal basis leaving numerous carrier, design and mission issues unresolved. These include:

- Venting of storage tank with payload bay doors closed
  - normal mission & mission abort (including anomalous conditions)
- Carrier selection (Hitchhiker - M baselined)
  - meeting 35 - 50 Hz natural frequency requirement
  - negotiating mass/cg constraints
- Fee drift of orbiter & desired thrusting for fluid settling
  - all drifting acceleration regimes result in bond numbers < 1
  - interface position and maintenance of stabilized interface
- NSTS safety requirements
  - no formal safety reviews held during this program phase
- NSTS ground operations (initial KSC contact/visit occurred in April 1991)
  - pre launch servicing
  - post landing (standard & emergency)
- Interfaces with GSFC and JSC (initial contacts/visits made)
  - follow up coordination hindered by no formal CONE program turn-on
- Accommodating storage tank high outflow on-orbit
- Impact of accommodating fluid transfer growth requirements
  - carrier space allocated for receiver tank and valve panel
  - experiment subsystem schematic accommodates these needs

2.0 INTRODUCTION

Martin Marietta has been under contract with the NASA Lewis Research Center to perform COLD-SAT Feasibility Studies since February 12, 1988. The baseline COLD-SAT activity was completed with the distribution of the final Phase A Study final report in August 1990.

On January 30, 1990 the authorization was received to initiate a Phase A/B Design Study for a Nitrogen On-Orbit Storage and Supply System Demonstration. A SOW was provided defining work for the Phase A of the effort which lasted 8 months and ended with a Concept Review in September 1990. Phase A included the following activities:

Subtask V.1 Project Management - This effort performed management functions and provided a management structure to plan, direct and integrate all requirements of the contract and SOW through compliance with schedules, technical and financial commitments of the contract. The task included control of costs and schedules, technical direction, reporting and preparing/participation in program reviews, control of documentation, and supporting program travel. This task covered the full 17 month period of performance of the CONE Task V effort of the main COLD-SAT Feasibility Study.

Subtask V.2 Payload Requirements Definition - This activity defined, in detail, the required system demonstration and experiment requirements using provided technical objectives for each. A Payload Requirement Document (PRD) and a System Specification were prepared as part of this effort. Preliminary hardware and operational requirements, fluid and thermal analyses, test procedures, instrumentation needs and timelines were generated during this phase. The first part of this subtask took 4 months and ended with a Preliminary Requirements Review (PRR) held on June 26 & 27, 1990 where task results were documented and presented. Other requirements assessments will be made prior to both the CR and SDR major reviews.

Subtask V.3 Payload Design Concept - This subtask performed the conceptual design of the payload systems, conducted trade studies, selected a carrier, and characterized the system with respect to operations, interfaces, configuration, backup up by supporting analysis and assessments. Updated PRD and System Specification documents were prepared. This task took 5 months and ended with a Concept Review where task results were documented and presented. This review took place September 18-19,1990.

Direction was received on 31 August 1990 authorizing the initiation of the Phase B effort for CONE. This activity lasted 9 months and included the continuation of Subtask V.1 and Subtasks V.4 and V.5 which are summarized as follows:.

Subtask V.4 Payload System Design - This subtask provided a system design of the agreed upon payload concept that resulted from the CR. This design process, including appropriate analyses, was conducted in parallel with the system demonstration and experiments requirements definition so that all defined system demonstrations and experiments are practicable and the payload is capable of achieving the requirements. A final PRD and system specification documents along with various supporting documents and reports were prepared. This task took 9 months and ended with a System Design Review (SDR) held May 29-30, 1991 where task results were documented and presented.

Subtask V.5 Project Report - At the conclusion of the CONE design study, a payload design study report was prepared that provided a comprehensive summary of the contracted effort. This effort took approximately three months. This study report is contained herein.

In October, 1990 a SOW was received along with a request for a change proposal to include an experiment for fluid transfer into the CONE program. This proposal was submitted and evaluated by NASA-LeRC and was not implemented due to a lack of funding.

This report addresses all aspects of the CONE system concept development which included the following:

a) Definition of the CONE payload approach concept and configuration which includes:
   1. Design evolution during the study.
   2. Experiment Subsystem definition and design.
   3. Support Subsystem definition and design.

b) Mission design and analysis considerations, requirements, and NSTS integration needs.

c) Experiment set goals and objectives for demonstration and experimental test requirements including the development of an experiment test data base for the on-orbit mission.

d) Mass properties data, weights, center of gravity information, and consumables capabilities.

e) Power, command and data requirements and capabilities.

f) Subsystem performance predictions.

g) Component and instrumentation assessments.

h) Ground segment design and requirements for mechanical and electrical equipment and facilities and ground control of the payload.

i) CONE system internal and external interface definition.

j) Generation of functional block diagrams and schematics.

k) Preliminary operational scenario development which included ground processing, launch pad, on-orbit, and post mission operational assessments, as well as contingency considerations and Payload Operations Control Center (POCC) support.

l) Preliminary safety analysis and Phase 0 flight/ground package preparation..

m) Discussion of technology issues.

n) Associated trade studies, analyses, and rationale.

o) Reliability analysis that led to a single string design.

p) Project planning and cost estimating activities.

2.1 Objective and Scope

The technical objectives and suggested experimental approach for the Cryogenic Orbital Nitrogen Experiment (CONE) contain both demonstration and experiment technical objectives which have been baselined to support very specific technologies relating to Space Station Freedom (SSF), various classes of earth and space based Space Transfer Vehicles (STV) and other related space applications. The objectives of the CONE experimental hardware are to collectively demonstrate the critical components and technologies required for on-orbit subcritical cryogenic fluid storage and supply, with a focus on pressure control techniques in a low-g environment. Both passive TVS and active mixing concepts of pressure control will be addressed from demonstration and experimentation viewpoints with active pressure control forming the highest priority of technology objectives. The performance of an autogenous pressurization system and a capillary surface tension liquid acquisition device will also be evaluated.

Figure 2.1-1 provides an overview of these objectives which are further defined below.

<u>Space Station Freedom Cryogen Resupply System Demonstrations</u> - These demonstrations will provide needed data to determine if Space Station consumables (N_2 and O_2) can be stored and outflowed in a subcritical state. Resupply of gaseous pressurant bottles where the commodities can be readily available for use on the Space Station using a liquid recharging technique will also be assessed. The unrelated issue of LAD performance and expulsion efficiency under nominal outflow conditions will also be evaluated as a demonstration.

<u>Technology Development by Controlled Experimentation</u> - Certain critical technology areas require in-space, low-g subscale testing as a confidence enhancement prior to commitment to a more sophisticated experimentally-orientated type of approach. Technology areas associated with maintaining tank pressure control and reducing thermal stratification by actively mixing the tank contents will be addressed. These experiments will provide needed answers to assist the design of the STV and in-space cryogen depot storage systems, as well as providing data and analytical correlation of models which will serve to mitigate the level of uncertainty associated with more advanced and refined experiments which can address critical issues unobtainable in the Orbiter environment.

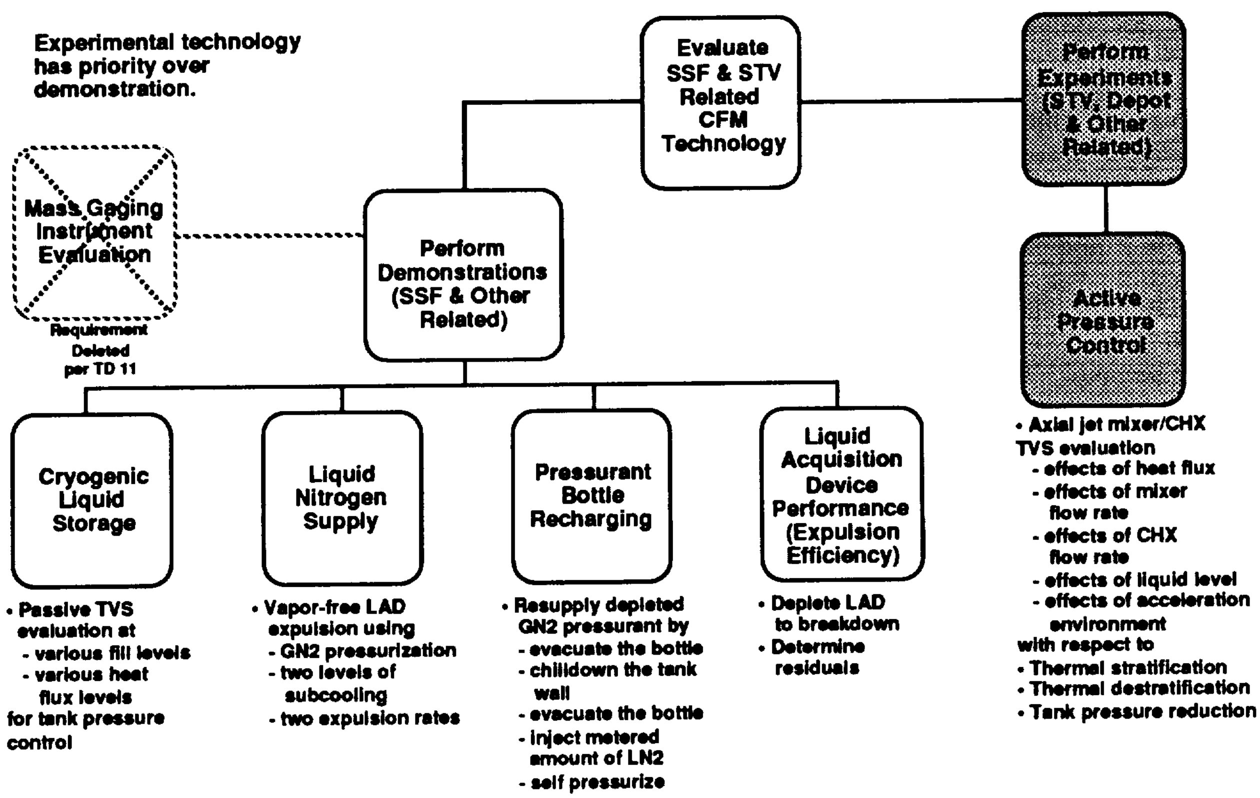


Figure 2.1-1 CONE Technical Objectives

The lack of the development of a cryogenic tank mass gage and the cancellation of the continuation of this program by JSC resulted in the deletion of the mass gage demonstration objective by NASA-LeRC.

2.1.1 Background and Need

Many important technological concerns have to be addressed in the area of cryogenic subcritical fluid management prior to the final design commitment for programs such as Space Station and STV. They include component, process, and subsystem interaction issues associated with various critical functioning elements of an integrated storage, transfer, and resupply system for on-orbit cryogens. Table 2.1-1 identifies key areas which require technology development, which have been expanded further in order of importance for each of the primary experiment areas of pressure control, no-vent fill, quantity gaging, and slosh dynamics. This technology priority list was prepared during the COLD-SAT Feasibility Studies and identifies those experiments, subsystems and processes which would most benefit from further ground development work prior to flight with the aim of enhancing the confidence of future system designs and providing near term benefits to current programs. Pressure control was the highest priority item on that list and is a significant objective of the CONE flight experiment.

Status of Cryogenic Fluid Management Technology Issues - Cryogenic fluid management technologies have been identified and examined throughout various studies by both NASA and contractors. Many ground tests and tests in drop towers and aircraft have been performed using actual cryogens and referee fluids. Orbital experiments, however, have been limited. Early flights of the Centaur upper stage were specially instrumented to obtain data on ullage and liquid heating rates, pressure rise, and vented mass. Early flights of the Saturn S-IVB stage demonstrated propellant settling and venting operations of a cryogenic stage, but instrumentation was limited.

Other flight experiments that have been performed were by NASA-LeRC using Aerobee sounding rockets to investigate self-pressurization rates in small liquid hydrogen tanks. In the early 1970's, Martin Marietta flew a liquid nitrogen subscale test tank in a KC-135 aircraft test for NASA-JSC. Flight durations for these experiments, however, were limited to seconds/minutes. We developed and flew the Storable Fluid Management Demonstration (SFMD) in 1985 that provided primarily visual data on fluid liquid motion behavior during tank filling in low-g. Apart from these efforts, however, orbital testing of many of the key cryogenic fluid management technology issues has not been performed to date. Ref 2-1 provides a chronological overview of these efforts.

2.1.2 Previous Work Overview

Planning for a comprehensive orbital test of these key technologies was begun in 1978 by NASA LeRC and Martin Marietta with the Cryogenic Fluid Management Experiment (CFME). These studies progressed to include fluid transfer with the Cryogenic Fluid Management Facility (CFMF). With the Space Shuttle Challenger accident, however, safety considerations have made the flying of liquid hydrogen on the Shuttle extremely difficult. As a result, alternate approaches have been developed resulting most recently in the completed COLD-SAT and CONE programs. Other options for orbital testing, using the Space Station for example, have also been examined. The following relates how the NASA activities in cryogenic fluid management technology combined with STS experimentation and demonstrations can be used to advance the overall long range objectives of cryogenic fluid management.

Table 2.1-1 CFM Development Items Priority List

I. Pressure Control

1. JT expander component development, characterization and reliability enhancement.
   - Tank pressure control is maintained by a thermodynamic vent system with both in tank and VCS heat exchangers.
   - The JT expander is the heart of the TVS concept. This device serves to meter the vent flowrate while reducing pressure in each heat exchanger. Additional heat capacity is provided due to the isentropic expansion across the expander and improves the performance of the TVS. Proper function has to be demonstrated.

2. Jet mixer pump/mixer approach component development and characterization.
   - Thermal stratification complicates pressure control
   - Mixing tends to promote vapor condensation and limit temperature gradients.
   - Pump and motor optimization is required to reduce pump size and power requirements.
   - Long-term use and cryogenic compatibility has to be demonstrated.

3. Integrated VCS/TVS heat exchanger design optimization including:
   a) Heat exchanger routing - both internal tank and external VCS
   b) VCS placement and insulation optimization
   c) Heat leak shorting issues
   d) TVS flow control optimization
   e) Support of large VCS to the PV and VJ
   - The effectiveness of a TVS/VCS can only be absolutely verified through developmental testing and analysis prior to baselining designs for flight.
   - Control of tank thermodynamic conditions depends strongly on the ability of the TVS/VCS/HX to be adequately designed.
   - Candidate designs need to be assessed prior to the development of a TVS system design.
   - TVS designs need to be developed that accommodate the function of pressure control for each of the tanker, depot, and OTV tank concepts.
   - Ground tests should be performed to verify 1-g performance of the designs to gain confidence that low-g performance will be adequate.

4. Minimize tank heat leak due to instrument lead wires which may include:
   a) Use of different wire material
   b) Development of in-tank data multiplexing capability
   - Improvement of tank heat leak levels is required for control of required heat flux and associated pressure control capability.
   - The hardware technology and techniques need to be developed and tested to verify the adequacy of the technology to perform this function.

II. No-Vent Fill/Refill

1. Spray nozzle/system characterization and optimization
   - Critical for chilldown, no-vent fill and certain mixing applications.
   - Spray flow patterns, delta pressure, droplet size, flow velocity, etc., require characterization for optimal performance through development testing.
   - Such requirements for each tank are different.

Table 2.1-1 CFM Development Items Priority List (Continued)

2. Transfer pump component development and characterization
   - Transfer pumps will enhance transfer performance by virtue of reducing the level of tank pressurization required and the amount of heat input to the tank from the addition of warm pressurant gas making the pressure control process easier to maintain.
   - Pump requirements have to be defined.
   - Candidate H/W needs evaluation for cryo operation.
   - Such things as power requirements, pump size, and reliability have to be optimized.
   - Prototype design testing is required.

3. Mass flow meter development and characterization
   - Accurate fluid inventories are required following transfer operations and outflows to define fluid usages.
   - Quality detection and determination is an added feature desired form these devices.
   - Device accuracy, repeatability, life, and sensitivity are all items needed development.

4. Provide for variation of LH_2 flow control to enhance the optimization of spray system performance.
   - Flow variability is one of the key parameters which is needed to optimize both tank fill and chilldown.
   - Various techniques require assessment.

5. The no-vent fill process has to be optimized and characterized within the operational constraints of working in one-g.
   - What techniques and spray combinations work best in one-g.
   - Rationale for use in low-g requires ground testing first.

6. Verification of the ullage exchange approach to tank fill/refill
   - No ground testing can be accomplished to support this technique.
   - Associated needs are transfer pump development and liquid/vapor detection.

III. Mass Gaging

1. Develop a low-g mass gage for subcritical LH_2 use
   - Accurate fluid inventories are required following specific spacecraft maneuvers, fluid transfer processes, and for long storage operations where fluid is both depleted and resupplied.
   - Issues of accuracy, repeatability and affect of fluid orientation and ullage geometry need resolution.
   - The type of gage to best meet these needs has yet to be determined.

2. Liquid/vapor sensor development and characterization
   - Liquid/vapor orientation is a desired measurement both as a verification of mass gage readings and for the determination of liquid/vapor position. To be used to characterize fluid motion within the tank in response to inflow, outflow and S/C maneuvers.
   - Incorporate liquid/vapor detection using temperature sensors so that dual sensor function can be provided.
   - Performance associated with wetting and drying out under low-g is an issued needing resolution.

Table 2.1-1 CFM Development Items Priority List (Concluded)

3. Determination of capability of a gaging technique to be used to determine liquid/vapor position under a settled condition so that tank liquid quantity can be determined.

IV. Slosh Dynamics

1. Liquid/vapor sensor development and characterization
   - Liquid/vapor orientation is a desired measurement both as a verification of mass gage readings and for the determination of liquid/vapor position. To be used to characterize fluid motion within the tank in response to inflow, outflow and S/C maneuvers.
   - Incorporate liquid/vapor detection using temperature sensors so that dual sensor function can be provided.
   - Performance associated with wetting and drying out under low-g is an issued needing resolution.

2. Develop a technique for measuring liquid slosh dynamic forces/loads being input to the system
   - In order to understand the effects of fluid motion on the S/C, the forces exerted on the S/C by the fluid are an important parameter.

3. Development of baffles to control slosh and determine baffle effectiveness and the damping afforded
   - Issues such as baffle size, location and attenuation characteristics require resolution.

V. General

1. LH_2 Valve Development
   - Already in work at MOOG under contract with NASA-LeRC.

2. Large, complex cryo tankage design, development, fabrication, and assembly to verify the interrelationship and interdependencies of all the parts to provide an optimized tank that performs required functions
   - Large LAD fabrication, installation and supportive testing and performance verification.
   - Improved MLI design, fabrication, installation.
   - Advanced composite strut/strap design, fabrication testing, and installation.
   - Characterization of optimal thermal stabilization methods using GHe injection or other techniques.

NASA Cryogenic Fluid Technology Development Program - NASA-LeRC has maintained a dedicated low-gravity storage, acquisition, expulsion, transfer and resupply development effort and supporting analytical modeling activity that has continued over the past 20 years and has been involved with numerous study, design and development programs during this time which included CFME, CFMF, and most recently COLD-SAT and CONE. In recognition of these technology needs, the focal point of this NASA Office of Aeronautics and Exploration Technology (OAET) endeavor has been the NASA Lewis Research Center (LeRC) Cryogenic Fluid Technology Office (CFTO) which has been a leading developer of low-g fluid management technology. More recently this activity has been directed, in terms of resources committed, to the more specific and inherently more complicated area of cryogenic fluid management (CFM) technology. The method to best obtain the required information has been intensively studied during the past 12 years and has recently (due to the Challenger accident) been redirected to be accomplished as a free flying ELV launched experimental spacecraft using LH2 as the best test fluid that encompasses all required normal cryogenic (excluding liquid helium) thermodynamics.

During this time, the prime objective has always been the same, namely, the development of a cryogenic fluid management database and experimentally verified analytical models which characterize the thermophysical processes associated with the on-orbit storage, transfer, and resupply of subcritical cryogenic liquids. Various future missions have been identified that require or would derive benefit from the development of this technology. Methods for obtaining experimental data to satisfy these technology needs have taken various directions over the years with the current emphasis being precursor CONE demonstrations and experiments prior to future LH2 in-space experiments.

Cryogenic fluid management technology requires a logical phased approach that includes the following:

1. All long term factors point to an integrated COLD-SAT type of flight experiment (or series of LH2 flight experiments) that will maximize the technological return for a minimal cost using LH2 as the test fluid with the following priorities.
   a. The experiment should be as simple as possible to accomplish the experiment objectives.
   b. Supporting hardware development items should be minimized or eliminated.
   c. Only experiments or demonstrations that require in-space low-g verification should be included.

2. A component development program to address mainly LH2 cryogen compatibility is required and is already in work at NASA-LeRC. This activity has to be expanded and maintained.

3. An integrated ground test program and approach is needed to provide as much characterization of the involved processes and associated component and subsystem interaction in a one-g environment. Such a program has been underway by both NASA and at Martin Marietta and other contractor's facilities over the years. An extensive LeRC test program is currently underway in the areas of subscale and large scale tank testing with LN2 and LH2 at Cleveland and Plum Brook facilities. Combined with their analytical modeling development, this test program makes LeRC the leader in this area.

4. Small subscale flight experiments of various types that are of specific and limited focus are required if they tend to mitigate risks associated with technology unknowns and, thereby provide enhancement to future LH2 experiments that are inherently more costly and result in greater program risk. These precursor experiments like CONE provide direct and timely benefits to Space Station Freedom and all classes of space transfer vehicles. CONE will answer basic CFM issues that will dispel skepticism and provide the foundation for more ambitious pursuits. Use of LN2 as the test fluid in the Orbiter payload bay as a building block type of approach prior to larger scale testing using LH2 has been a philosophy that we have advocated for many years. As early as 1985 we proposed such an LN2 experimental approach to NASA Headquarters.

2.2 Justification for the CONE Payload

Martin Marietta in consonance with the NASA Lewis Research Center has long recognized the need for efficient, effective, and reliable management of subcritical cryogenic fluids in the reduced gravity space environment. Fundamental data required for the understanding and design of systems to meet this need are lacking. Subscale STS Orbiter experiments and demonstrations can provide increased confidence that planned approaches for the implementation of subcritical storage and supply of Space

Station consumables can be accomplished. This information will help ease technological concerns associated with specific key areas, thereby reducing the risk for more advanced integrated cryogenic on-orbit experiments that would use LH2 as the test fluid. Precursor experiments like CONE would also provide data that would be a confidence enhancement to the Initial Space Transfer Vehicle (ISTV) in the area of active pressure control of vehicle tankage.

The United States' space program is entering an era of expanded space presence and activity with Space Station Freedom and future near earth, lunar and interplanetary exploration missions which will require the use of cryogenic liquids for propulsion, life support, power reactants, thermal control and sensor coolants, and experiment or manufacturing process consumables. For efficient, reliable and cost-effective long term space operations, these applications will require integrated storage and transfer systems capable of providing thermal control, fluid management, pressurization and venting, and fluid transfer and resupply of various cryogens in the reduced gravity space environment. This environment creates technical design challenges that are dependent on both enabling and enhancing subcritical cryogenic fluid technology data that can only be obtained by in-space experimentation.

These needs have provided the impetus to pursue this technology in a timely manner to support the design efforts of programs that require or derive benefits from the development of this technology. This lack of technology development has resulted in the continued use of outdated and weight intensive supercritical cryogen storage that is not life cycle cost (LCC) effective. If just a small subset of this technology were available today, Space Station Freedom could be saving hundreds of pounds in LN2 and LO2 storage weight. A similar weight savings would occur in the Logistics Module that would translate into multimillion dollar LCC savings. All foreseeable lunar and planetary exploration initiatives make use of extensive quantities of cryogens for propulsion and life support that have to be maintained and efficiently utilized in space. Decisions are being made today that greatly impact system configuration and operational effectiveness based on not having to advance the state of the art in cryogenics. Commitments have to be made now to forestall the technology inertness that has troubled the space program for many years.

Flight Experiment Benefits and Approaches - The development of low-gravity fluid management technology has been hampered by the lack of adequate test facilities. Earth based test methods provide only short periods of low-gravity. For example, drop tower tests last only a few seconds, aircraft based tests last about 30 seconds, and a suborbital rocket will provide a few minutes. While such tests have allowed significant advances in the understanding of low-gravity fluid behavior, they do not provide the confidence needed to design cryogenic storage and transfer systems that must function as efficiently as possible for extended periods under low-gravity conditions.

The need is for low-gravity test periods on the order of hours/days, for which orbital tests are required. There are a number of ways of placing experiment packages into orbit, with varying abilities to satisfy the experiment requirements. Four criteria for evaluating the methods have been used in supporting the overall needs of the COLD-SAT and CONE programs, namely technology return, cost effectiveness, risk, and timeliness.

Technology return refers to how well the experiment would address the objectives of the fluid management development program. Objectives impose specific requirements on the configuration of the experiment if all are to be performed. At least two tanks, supply and receiver, are needed. Most likely the tanks will not be full-size, but they need to be sized so that the scaling ratios remain reasonable. Background accelerations of 10^{-6} g or less are desired, but somewhat higher levels can be accommodated. To perform thermal performance tests, a means of applying a specified acceleration is needed. Tests with an actual cryogen are preferred since it is the only way to obtain the large temperature differences and provide the effects of heat and mass transfer on tank pressure control. Referee liquids can simulate various aspects of the storage and transfer of cryogens and scaling helps, but complete simulation is not possible. Vent and pressurization systems are needed. The experiment must address as many of these objectives as possible and provide data that can somehow be applied to a full-scale cryogenic system.

Cost effectiveness relates the technology return and the cost of the experiment. An inexpensive experiment that meets only a few objectives can be as cost effective as a very expensive experiment that covers more technology areas. By providing risk mitigation and by spreading out resources a single large commitment that could fail is avoided.

Risk is concerned with the probability of the experiment to perform its mission. An expendable experiment could be lost with no results, while a retrievable experiment, at the worst, may be flown again. This criteria must consider the reliability of the launch vehicle and experiment in comparison to its cost.

The timeliness considers how soon the launch opportunity would be available. Priorities will play a significant role when there is competition for limited launch resources, such as the Shuttle.

Regardless of the specific on-orbit fluid management experiment concept, it is only of value if the resulting data and observations can be applied to the design of a full-size system. In some cases, it will be possible to directly apply the test results. For example, an actual component or instrumentation system could be tested with the actual fluid and the results would be directly applicable. If the actual fluid cannot be used, as is the case in many instances with liquid hydrogen due to safety considerations, then selection of the referee fluid and the sizing of the experiment hardware are crucial to the usefulness of the data obtained in a subscale experiment.

When the fluid properties and/or the experiment geometry differ significantly from the full scale system, then scaling methods using dimensionless parameters that characterize the key physical processes must be used. In many cases, however, is is not possible to design an experiment so that all of the important dimensionless groups are maintained constant or within the same regime as the full scale system. In these cases, the most promising approach is to use a mathematical model that attempts to simulate the experiment. Data obtained from the subscale experiment can then be used to verify analytical modeling ability to predict key processes even though not all of the key dimensionless groups are scaled. Understanding the scaling issues associated with the design of subscale orbital fluid management experiments and recognizing the importance of scaling to the technology return aspect of the experiments is crucial. Therefore, scaling will be an important factor in the assessment of the various experiment concepts particularly with respect to the CONE.

We have been involved with the evaluation of various experimental options and their ability to satisfy both primary (enabling) and secondary (enhancing) experiment objectives. These objectives (developed for the COLD-SAT program) provide the greatest technological return and serves as a measure of the cost effectiveness of other approaches that only address a portion of the technology. A comparison of various experiment options and their ability to satisfy the CFM primary and secondary objectives is presented in Table 2.2-1. The main assumption used in formulating this table was that the different experiment options would be required to perform experiments similar to those of COLD-SAT. This table represents a go, no-go ability of the different options to perform the various experiments (shown by an X) and does not consider the important criteria of technology return, cost effectiveness, risk, and timeliness. Such criteria are crucial in assessing the usefulness and viability of the option. Some of the options that we and others have assessed include:

> Space Shuttle Attached Payloads - The shuttle is being used to carry a wide range of experiments into orbit. For attached payloads, the acceleration environment includes various disturbances due to orbiter operations that does not provide the most suitable of conditions, making 10^{-4} to 10^{-6} g a typical acceleration, but there will be peaks of 10^{-2} g. Use of

Table 2.2-1 CFM Experiment Options Comparison

Fluid Management Experiments	Space Shuttle Attached					Space Shuttle Deployable		Space Station			Scout & Pegasus	Centaur
	GAS	Hitchhiker	Middeck	Spacelab	Cargo Bay	GAS	Eureca/Spartan	Lab Module	Attached To Truss	Coorbiting Platform		
<u>Primary Experiments:</u> Low Gravity Tank Pressure Control						x	x			x	x	
Tank Childown in Low-G	x	x		x	x	x	x				x	
Low-G No-Vent Fill and Refill of Tanks	x	x		x	x	x	x				x	
Total Communication LAD Fill/Refill Characteristics	x	x	x	x	x	x	x	x	x	x	x	
Liquid Mass Gaging in Low-G	x	x	x	x	x	x	x	x	x	x	x	x
Liquid Dynamics and Slosh Control	x	x	x	x	x	x	x				x	x
<u>Secondary Experiments:</u> Tank Thermal Performance						x	x			x	x	
Pressurization With Hydrogen and Helium	x	x		x	x	x	x		x	x	x	x
Direct Liquid Outflow With Low-G Settling	x	x	x	x	x	x	x	x	x	x	x	x
Liquid Acquisition Device Performance in Low-G	x	x	x	x	x	x	x	x			x	
Transfer Line Childown in Low-G	x	x		x	x	x	x		x	x	x	
Control of Liquid Subcooling During Outflow	x	x		x	x	x	x		x	x	x	
Liquid Dumping in Low-G	x	x		x	x	x	x		x	x	x	x
Advanced Instrumentation for Cryogens in Low-G	x	x		x	x	x	x		x	x	x	x
Fill of Partial LAD in Low-G	x	x	x	x	x	x	x	x	x	x	x	

anything other than benign test liquids (e.g. water, liquid nitrogen, and liquid helium) would require considerable effort to meet the stringent safety requirements. The size could range from the five cubic feet available for a getaway special can to the full cargo bay. Support systems, such as data recording, attitude control, electrical power, and thermal control, are available. These payloads will be returned to Earth, so they could be reused or salvaged. Mid Deck and Spacelab experiments offer unique opportunities because an operator can be involved who can directly observe, react to the unexpected, modify procedures, and repair equipment, greatly enhancing the technology return and cost effectiveness, while reducing risk. With regard to technology return, all shuttle experiments would be deficient in technology return to some degree since they most likely would not be able to use liquid hydrogen. Also, smaller Shuttle experiments would have more limited objectives due to scaling issues than those that are large. Additionally, the experiment could suffer from added weight and complexity due to the necessity of man-rating. Manifesting an experiment on the Shuttle is a lengthy process as well, with even simpler experiments in the Hitchhiker-G class taking nearly two years from the time of flight assignment to launch. However, unless a dedicated Shuttle launch was needed, the sharing of costs makes some shuttle experiments very cost effective.

In satisfying the CFM test objectives, the prime limitation is on the flight duration. Current Shuttle missions last between five and seven days which is of insufficient duration to completely perform many of the CFM tests. Compromises in objectives have to be made to accommodate these time constraints.

Space Shuttle Deployable Payloads - The advantage of a deployable payload over an attached payload is that the orbiter disturbances and time limitations are eliminated so the desired low-gravity is obtained. However, the payload must now provide its own support systems. Retrieval is an option, but it would increase operations costs. Also, as with Shuttle-attached concepts, only non-reactive cryogens could be used as test liquids and the man-rating requirements would still have to be satisfied. Some free-flying spacecraft are being designed for Shuttle launch, deployment, and retrieval. Among these are the Spartan and the European Eureca platform. The Eureca, in particular, is designed to be launched and deployed by the Shuttle, providing resources for piggy-back experiments for up to six months in orbit after which it is retrieved by the Shuttle. Such platforms could make attractive options for long duration, low gravity fluid management experiments but the ability to use the platform's propulsion system to induce varying accelerations could be limited by the requirements of other experiments present on the carrier. If full use of the deployable platform were possible, however, may of the required CFM tests could be performed. Use of these carriers is quite expensive and typical costs for a 454 kg (1000 lb) experiment exceed $100M.

Space Station - One of the primary purposes of the Space Station will be to provide the means of performing orbital experiments when the Station becomes operational. Smaller experiments can be accommodated in the laboratory module where they can be man-tended, and support systems are available. Larger experiments can be attached to the truss, losing direct observation but still having access to support systems. The accelerations would be lower than those of shuttle, but operational disturbances would still be present. The co-orbiting platform will provide isolation from disturbances and a way of applying specific accelerations, but an autonomous payload is required.

Ultimately the Space Station would seem to offer the most effective experiment, considering all factors with the exception of timeliness. A truss mounted module could be of a generous size, be operated for extended periods, be repaired and modified (in space or on Earth), and be resupplied. A trade-off between the accessibility of the experiment and the need for applied accelerations would determine the choice between a truss mounted and co-orbiting platform experiment. The biggest advantage of the Space Station is its ability to provide an experiment with all of the necessary utilities such as power, data management and control, and some limited fluid interfaces which will significantly simplify the experiment. The CFM tests that could not be performed on the Station appear to be those associated with fluid motion control and pressure control experiments under varying accelerations since application of accelerations would require thrusting of the entire Space Station. Using liquid hydrogen as the test fluid is also an issue. Currently only non-reactive cryogens could be used.

Small Satellite Experiment Packages - Various expendable launch vehicles (Atlas, Delta and Titan) could place a large, experimental satellite, such as COLD-SAT, into orbit. Other, smaller scale satellites, however, could be launched with a less expensive booster such as the Scout. Scout can carry ~ 227 kg (500 lbs) into low earth orbits. Compared to COLD-SAT, the tank size and maneuver capability would have to be scaled back considerably and be limited in scope severely impacting the technology return and cost effectiveness. While safety would still be an issue with Scout, the experiment could use hydrogen.

Pegasus is an air launched vehicle, commercially developed, that can boost 318-454 kg (700-1000 lbs) payload into low earth orbit. Fluid management experiments in this class would be similar to those designed for the Scout vehicle, although the Pegasus provides a larger fairing and more payload capability. Over a series of missions, all of the COLD-SAT experiments could be performed by this class of experiment since they would be miniature versions of the COLD-SAT spacecraft. However, this assumes that sufficient hardware to perform the tests could be packaged in the limited payload capacity and volume and requires the development of a lite-sat class of spacecraft bus. Data scalability due to the small size of the tanks makes Scout and Pegasus experiments using LH2 concepts that mitigate risk, but do not replace a full-up COLD-SAT type of experiment.

Centaur - The Centaur is an existing cryogenic upper stage that could be employed as a test bed for performing cryogenic experiments after its primary mission is completed. It would be similar in scale to COLD-SAT since a large expendable launch vehicle would be needed to put the Centaur into orbit. Being able to use an "off-the-shelf" spacecraft could contribute to the cost effectiveness but the testing that could be accomplished would be limited by the amount of hydrogen left after the primary mission. Also limited testing time would be available since the Centaur is not thermally efficient and the extra experimental hardware that would have to be added to the stage. The addition of such test hardware can only be considered for certain missions where propellant margin is available and where such addition has been agreed to by the primary payload (a task that may not be easily obtained). Such an approach is very costly and provides minimum technology return since the period of testing time on orbit is limited to 8-16 hours unless additional power is provided. Approaches where the Centaur is converted into a test vehicle where the test hardware is the payload are very costly and again are limited to test time due to power and LH2 limitations (Ref 2-2).

In assessing these various options the issue of technology return, cost effectiveness, risk, and timeliness have to be weighed in selecting the best approach to follow. The perfect CFM experiment has not been proposed nor can it be designed within cost limitations of today's fiscal environment. The component development, ground testing, and precursor subscale flight experiments that was previously discussed provides an orderly approach to the problem. The time has arrived to proceed with a flight experiment. CONE provides a means to accomplish this end and is the best compromise of the available options discussed in this section and summarized in Table 2.2-1. Table 2.2-2 provides an assessment of the available options for CFM flight experimentation. An STS attached payload such as CONE provides an approach that maximizes a low to medium technology return by being highly cost effective, low risk and having a good timeliness. It is highly focused, uses a non reactive cryogen, flies as a Hitchhiker-M class of experiment and supports both Space Station Freedom and Space Transportation Vehicle cryogenic technology needs, as well as other generic needs of space depots, tankers, and other related systems. Hardware recovery for possible reuse is also a big plus.

While cryogen transfer and resupply to a user tank is currently not a part of the technical objectives, we believe that such a requirement could be accommodated by CONE and accomplished in a single Orbiter mission.

Table 2.2-2 Assessment of In-Space Experimental Options

	TECHNOLOGY RETURN	COST EFFECTIVENESS	RISK	TIMELINESS
SPACE SHUTTLE ATTACHED PAYLOADS	M-L	H	L	H-M
SPACE SHUTTLE DEPLOYABLE PAYLOADS	H-M	L	M	M
SPACE STATION	M	M	M	L
LARGE SATELLITE EXPERIMENT PACKAGES*	H	H	H	L
SMALL SATELLITE EXPERIMENT PACKAGES*	M-L	M	M	H-M
CENTAUR	M-L	M-L	M-H	M

* ELV LAUNCHED
H = HIGH
M = MEDIUM
L = LOW

2.3 Design Guidelines, Groundrules and Priorities

A set of design guidelines was established for the purpose of providing top level guidance for the development of the the CONE payload approach concept. They represent a set of groundrules and goals addressing the nature of the CONE System, the proposed payload carrier that will be used to support the payload in the Orbiter cargo bay, how it has to operate and interface, and how related issues, requirements, and priorities were established and handled early in the program to create a reference set of baseline intent.

The following top level design decisions represent given, implied and derived basic features which were used in the development of the CONE concept:

a) A maximized total technology return for a minimum total system cost.

b) Maximize reliability for the proper execution of mission objectives for a standard seven day mission by using a baseline single string approach.

c) Minimize technological risk through the use of existing hardware and proven designs and approaches.

d) Maximized use of Orbiter standard services and interfaces.

e) Maximized use of existing test facilities, processing capability, and launch services.

f) Use of the Hitchhiker-M (HH-M) as the payload carrier.

g) Use of the HH-M avionics unit for power/command/data interfacing.

h) Primary uplink/downlink communications with the CONE payload using NASCOM and standard services provided by the NSTS.

i) Minimize launch weight with a 20 % contingency.

j) The design will accommodate three reflights.

k) The design will be modular for simplicity and for ease in carrier integration.

l) The design will include provisions for fluid transfer expansion and the addition of a receiver tank and associated components.

m) The LN2 storage tank will be scaled where possible to applicable criteria and will be sized as small as possible to meet passive TVS testing needs.

n) The mission will be accomplished during a standard seven day or less flight.

o) The system must meet safety requirements of NSTS 1700.7B.

p) Minimize crew participation.

2.4 Potential Payoffs/Benefits

The replenishment of spacecraft cryogenic consumables provides an increasingly attractive method for extending the useful life of spacecraft on-orbit. A wide variety of orbital cryogenic liquid storage and supply systems are defined in current NASA and DOD planning. These systems vary in size from small cooling applications to large chemical propellant and electrical orbital, lunar, and interplanetary transfer vehicles, on-orbit depots and resupply tankers. Many of these applications will make use of in- space cryogenic storage or will require orbital transfer of cryogens for replenishment of spent or depleted systems. Initial loading of these systems in space may also be required, creating various initial thermal conditions from completely cold to warm, which require precooling childown operations. All of these needs have the common requirement of low-g fluid management to accomplish gas-free liquid expulsion, transfer, and resupply and efficient thermal control to manage heat leak and tank pressure. The focus of the CONE Program is to develop the basic technology required to meet the needs of storage and tank pressure control for the purpose of establishing an adequate technology base to enable the design and operation of those systems utilizing subcritical cryogenic fluid in the reduced low-g space environment . The CONE payload will be utilized to develop the technology required to effectively manage cryogens in space by performing a series of cryogenic fluid management flight experiments. These experiments will provide essential low-g data to enrich the understanding of the thermophysics of subcritical cryogens and to validate analytical and numerical models. The technology developed will permit the establishment of a cryogenic data base containing methodologies and criteria for in space subcritical cryogenic system design.

These needs have provided the impetus to pursue this technology in a timely manner to support the design efforts of programs that require or derive benefits from the development of this technology. This lack of technology development has resulted in the continued use of outdated and weight intensive supercritical cryogen storage that is not life cycle cost (LCC) effective. If just a small subset of this technology were available today, Space Station Freedom could be saving hundreds of pounds in LN2 and LO2 storage weight with increased safety due to lower system operating pressure. A similar weight savings would occur in the Logistics Module that would translate into multimillion dollar LCC savings. All foreseeable lunar and planetary exploration initiatives make use of extensive quantities of cryogens for propulsion and life support that have to be maintained and efficiently utilized in space.

Many important technological concerns have to be addressed in the area of cryogenic subcritical fluid management. Key areas which require technology development include pressure control, no-vent fill, quantity gaging, and slosh dynamics. Technology priority lists have been assembled that identify those experiments, subsystems and processes which would most benefit from further development work prior to flight with the aim of enhancing the confidence of future system designs and providing near term benefits to current programs. Pressure control was the highest priority item on that list and is a significant objective of any on-orbit experiment and forms the highest technical CONE priority .

The CONE payload will provide an opportunity to demonstrate the feasibility of combining various methods of integrating pressure control, liquid acquisition, and tank fluid outflow into a subscale experimental tank design that will provide subcritical LN2 storage and outflow characterizations. Controlling tank pressure and supplying single-phase liquid to accomplish transfer and resupply/topoff of tankage is essential to having a space-based operational capability. Using LN2 as the test fluid will provide data acceptable for both oxygen and nitrogen subcritical systems and provides for extrapolation to LH2. In addition, LN2 allows collection of needed cryogenic data without the safety implications associated with liquid hydrogen (LH2) while operating in the more restrictive post-Challenger era of payload safety within the Orbiter cargo bay.

Subcritical cryogenic fluid management technology for cryogens stored at low pressure contains many elements which are required to successfully support future space system development and mission goals associated with the cost of system operation and reuse. One of the technical elements is a knowledge of low-g transfer phenomena which is critical since in-space systems are currently end-of-life limited by depletion of on-board consumables. A more basic element of the technology, however, is an understanding of the storage, tank pressure control and tank outflow requirements for subcritical cryogenic fluids. CONE technical objectives are concentrating on these top-level basic elements and has the potential for expanded CFM capabilities.

Exclusive of Centaur, existing cryogen storage and supply systems utilize well characterized supercritical techniques that are outdated and weight intensive due to the high pressure required to assure that a single phase is maintained in the tank. Substantial weight savings can be realized by low pressure subcritical storage where two phase fluid is stored and liquid only is provided to a user by a surface tension liquid acquisition device (LAD). CONE on-orbit testing in the areas of liquid storage, using both active and passive techniques to control tank pressure, along with the assessment of supplying vapor-free LN2 from the tank by use of a LAD is the first step towards the implementation of future in-space subcritical cryogen use.

2.5 Design Approach and Methodology

Our approach for the conceptual Phase A/B design study for the CONE was to produce a cost effective and technically suitable payload design which accomplished the defined demonstration/experimental and mission objectives while incorporating the established design guidelines, groundrules and priorities. In particular, our efforts concentrated upon the effects of the low-g space environment, NSTS and carrier constraints, and mission duration (a maximum of five days of testing time) on the cryogenic storage, acquisition, and supply technologies which are critical to the CONE program. Key towards this end has been the application of systems engineering techniques to optimize the total system design in terms of performance, cost and mission compatibility with the Orbiter, as well as insuring that contract/SOW requirements are met. A broad spectrum of engineering disciplines are necessary for a system as complex as CONE. The systems engineering approach serves to tie the process together, permits the rapid identification of problems, inhibits a drifting from system objectives, and allows recognition of process completion through required program reviews, technical interchange and customer agreements.

The extensive nature of the experimental requirements and Orbiter/carrier integration created a systems requirements definition dominated by the need to accommodate STS/carrier payload integration to best accomplish these technical objectives. As a result, the experiment subsystem, mission science and Orbiter/carrier interfaces drove the support subsystems design and payload configuration in the following major areas:

- data acquisition and control
- structures
- venting scenario
- tank shape and orientation

Table 2.5-1 shows some of the key requirements that were used to design the CONE and the rationale for why these requirements are drivers of the design or mission operations. Many impact more than one discipline; collectively they demonstrate the complexities associated with the systems engineering activity. Even though there are many design drivers identified, both given and derived, which cover a broad range of experimental and mission needs, it is important that the design resulting from the trade studies, analyses, and experiment desires not result in a payload that is overly sophisticated and costly. Rather, the design should present a realistic compromise between payload and experiment subsystem complexity, weight, development requirements, life cycle costs, and how much of the desired potential mission and on-orbit testing can be accommodated with imposed Orbiter/carrier constraints.

Table 2.5-1 Requirements That Drive the CONE Payload Design and Rationale

Requirement	Rationale
1. Supply tank volume	1. Heat flux scaling criteria and time to accomplish passive pressure control
2. Settle tank fluid (Duration and number of times)	2. Orbiter propellant allocated for payload operations
3. Maintaining fluid position	3. Orbiter duration for fixed attitudes
4. Payload total weight	4. Hitchhiker-M capability
5. One kbps data rate	5. Availability of Orbiter data for downlink
6. Mission duration (approx 5 days)	6. Standard Orbiter mission
7. Single string system	7. HH-M is single string, plus single string provides a reliability for the mission duration of greater than 98%

The design study consisted of the following three subtasks:

<u>Payload Requirements Definition Methodology</u> - The top-level logic flow presented in Figure 2.5-1 follows the definition provided in the SOW for this subtask and utilized proven system engineering techniques to develop the system requirements derivation needed as the output of this task. Payload requirements were generated using past experience and data bases from other STS payload programs

along with the technical objectives defined in Appendix A of the SOW. STS requirements were iterated with payload requirements to insure compatibility and resulted in the development of a baseline set of system demonstrations and experiment requirements. A Preliminary Requirements Review was held.

Preliminary fluid and thermal analyses were performed to support the development of experiment subsystem requirements in each of the defined areas, established performance requirements and measurement needs, and resolved conflicts. The result was the development of a strawman concept that satisfied the requirements. A strawman mission and associated timeline were also developed.

Associated support system requirements were derived and iterated to interface with Orbiter provided services that met program objectives and mission goals. Additional considerations included compatibility assessments with Orbiter accommodations and operational constraints along with environmental and interface assessments.

Requirements were documented in a Payload Requirements document (PRD) and a Payload System Specification. The PRD contains the science needs for the payload while the System Specification contains the top-level system requirements.

Payload Concept Design Methodology - The top-level logic flow presented in Figure 2.5-2 follows the definition provided in the SOW for this subtask and utilized proven system engineering techniques to take the system requirements derivation and develop the conceptual approach that best meets these requirements. The baseline set of system demonstrations and experiment requirements were updated and iterated against payload and STS requirements. These requirements were then allocated between hardware, software, and interface elements needed to perform the on-orbit system demonstrations and experiments.

Refined fluid and thermal analyses were performed to support development of experiment subsystem conceptual definition in each of the defined areas, established performance requirements and measurement needs, and resolved conflicts. The result was the development of a concept that satisfied the requirements. A conceptual mission and associated timeline was also developed. Associated support system requirements were derived and iterated to develop support subsystem concepts that interface with both recommended Carrier and Orbiter provided services that are needed to meet program objectives and mission goals.

Requirements were documented in updated issue 2 of the Payload Requirements Document (PRD) and Payload System Specification. A Conceptual Review (CR) was held at the end of the task.

Payload System Design Methodology - The top-level logic flow presented in Figure 2.5-3 follows the definition provided in the SOW for this subtask and utilized the system requirements derivation and the conceptual approach to produce a preliminary system design for the payload. STS requirements were iterated with payload requirements to insure compatibility and resulted in the refinement of the CR baseline set of system demonstrations and experiment requirements. These updated requirements were then allocated to hardware, software and interface elements needed to perform the four on-orbit system demonstrations and one system experiment.

This task concentrated on providing information relevant to the design of the payload with supporting analyses in areas of specific interest and was supported with preparation of extensive documentation.

Requirements were documented in a Payload Requirements Document (PRD) and a Payload System Specification. The PRD contains the science needs of the P/L while the System Spec contains the top-level system requirements. Both documents have been updated since the CR and released as Issue 3 for the SDR. A System Design Review was held at the end of the task and was the final review for the study.

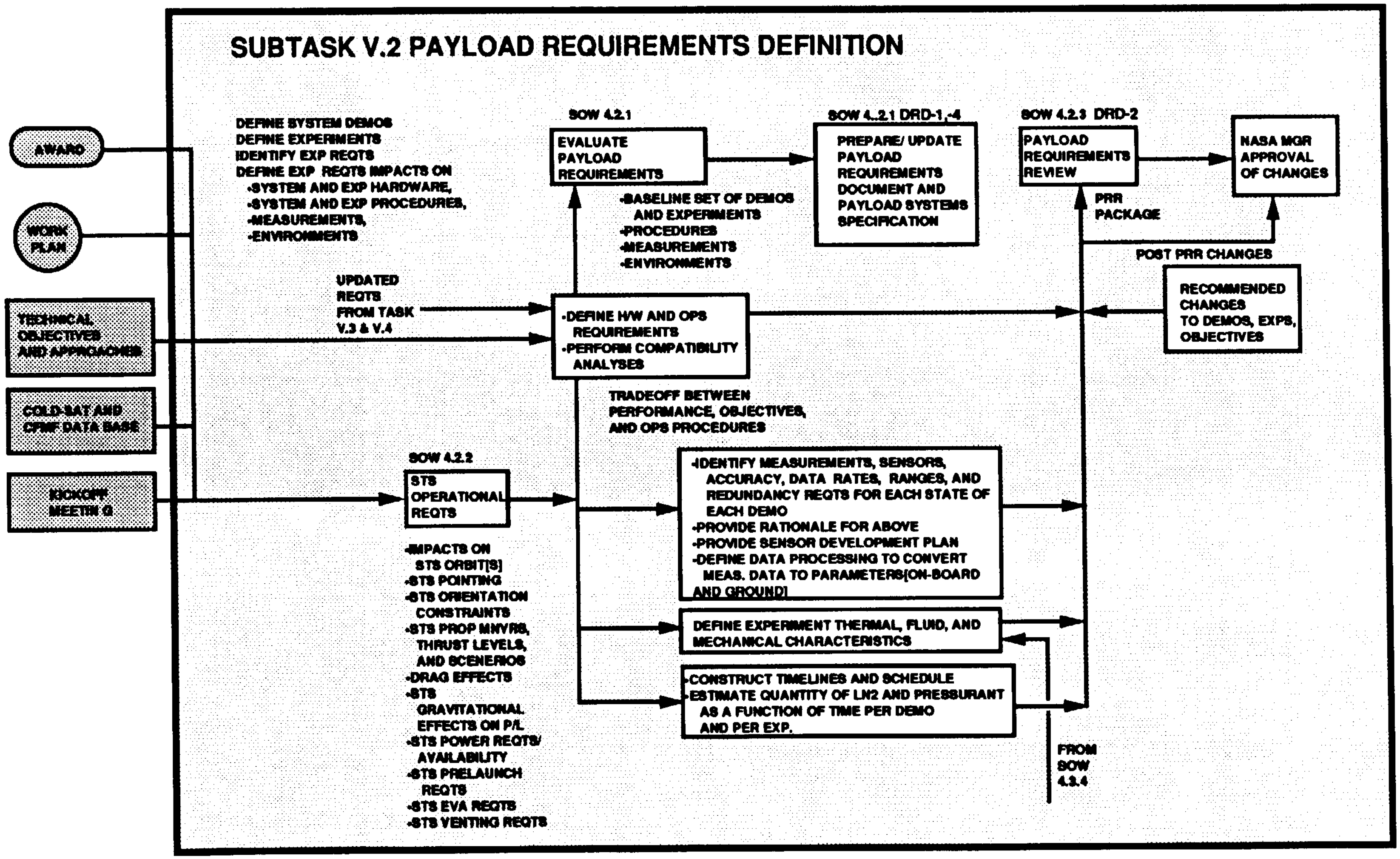


Figure 2.5-1 Subtask V.2 Preliminary Requirements Definition - Detailed Task Flow

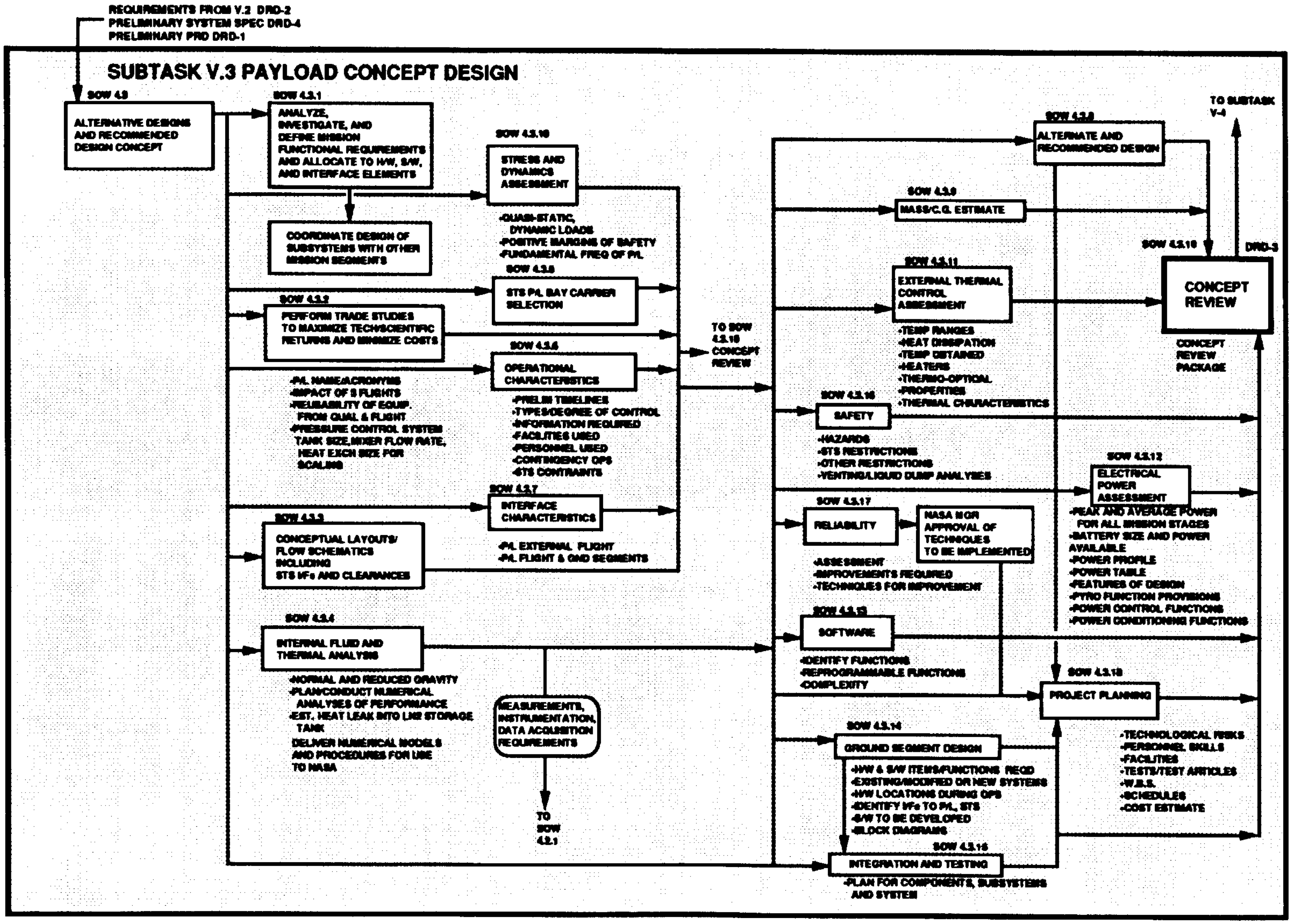


Figure 2.5-2 Subtask V.3 Conceptual Design - Detailed Task Flow

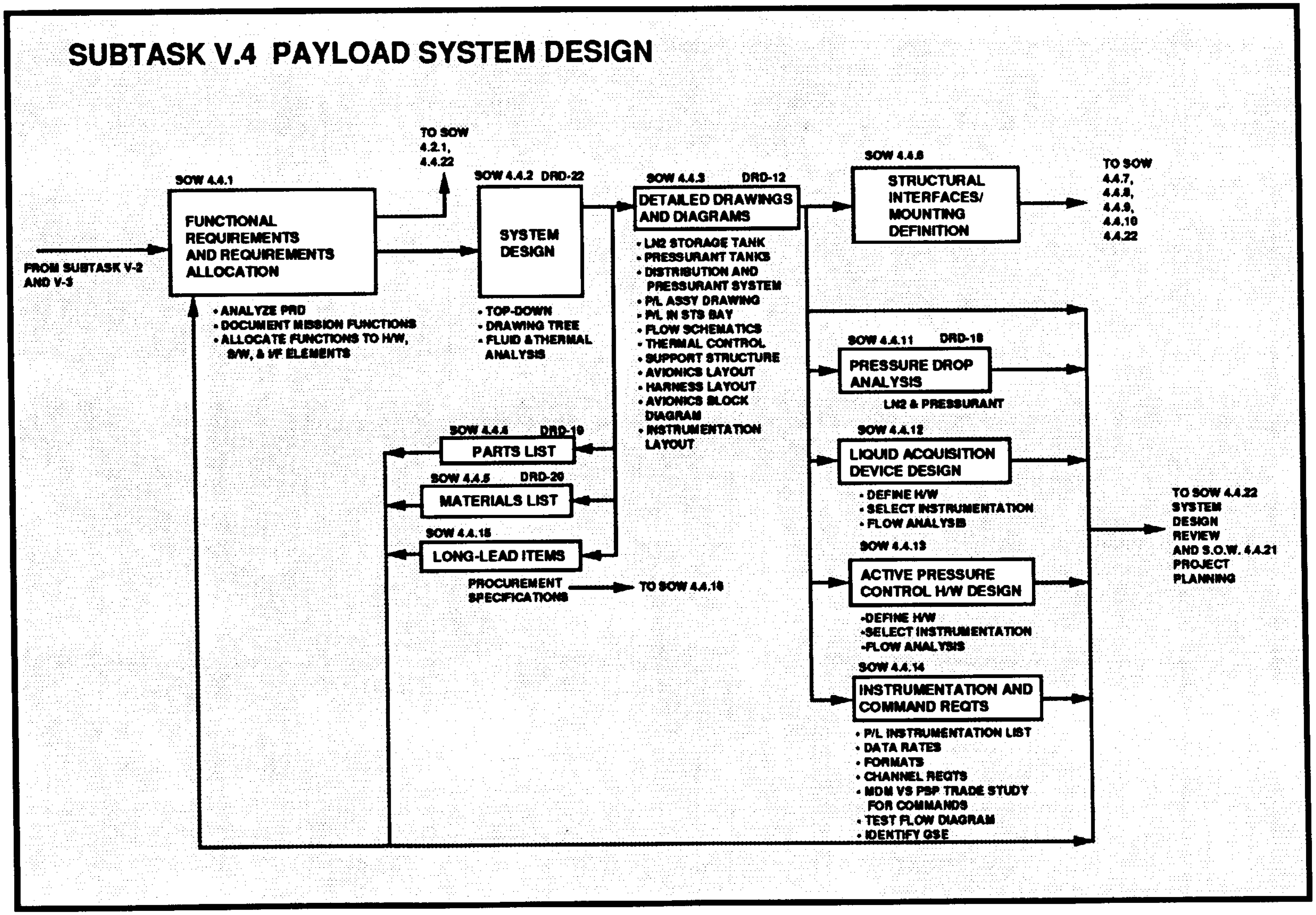


Figure 2.5-3 Subtask V.4 Payload System Design - Detailed Task Flow

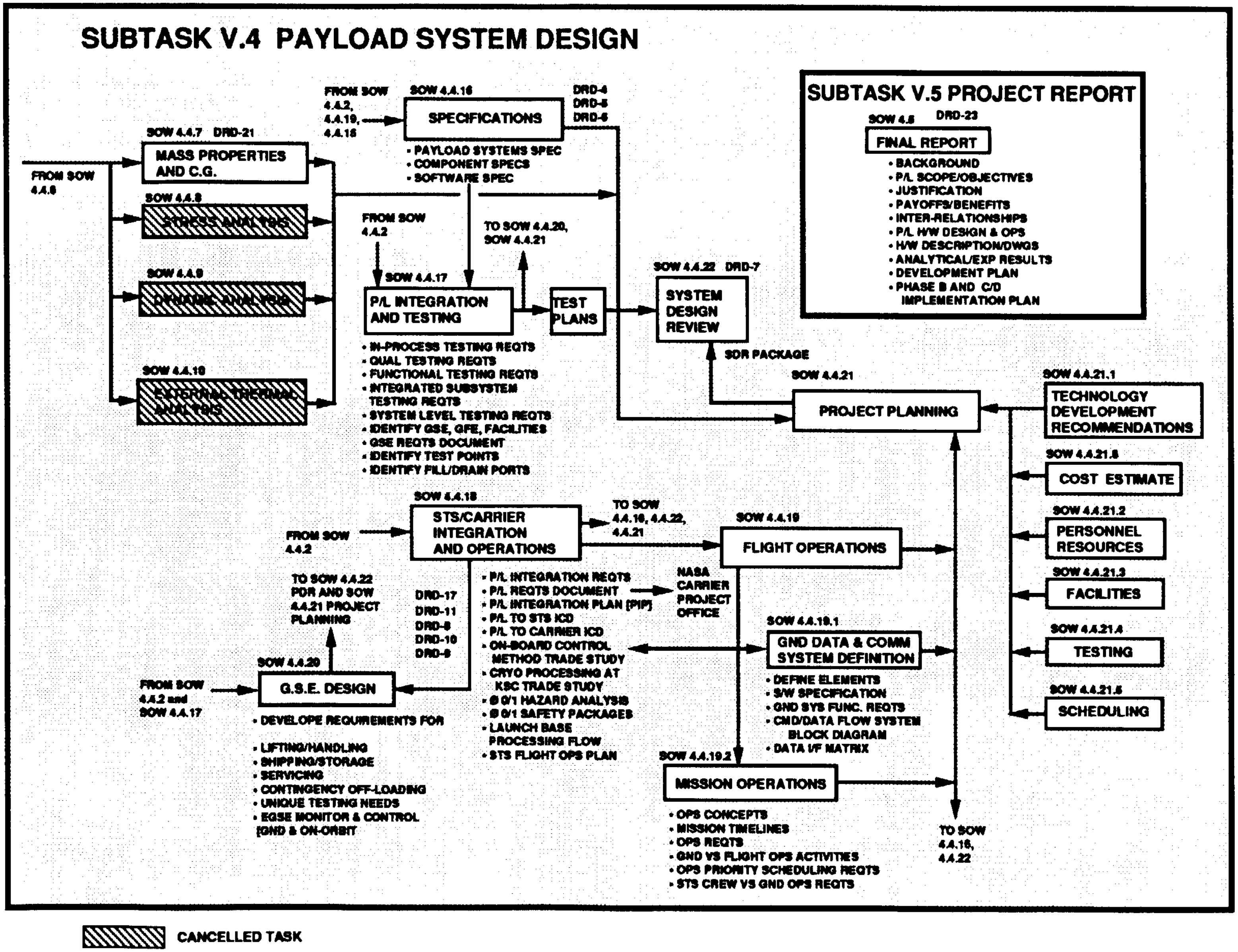


Figure 2.5-3 Subtask V.4 Payload System Design - Detailed Task Flow (Concluded)

CONE Engineering Analyses (EA's) - In the area of supporting documentation we have continued the COLD-SAT initiated practice of compiling additional information, trade study results and other analysis into separate packages which have come to be termed Engineering Analyses (EA's). Over 50 of these analyses have been produced and submitted to NASA-LeRC.

CONE Hitchhiker-M Payload - The CONE configuration shown in Figure 2.5-4 forms our baselined preliminary system design approach for the payload and is the output of the system design effort. Throughout this report design information, analysis and trade study particulars are presented which support the definition of this approach and the use of the HH-M as the carrier of choice.

Design features of this concept include:

- An integrated experiment subsystem that consists of two valve panels and a LN2 storage tank that is handled and integrated to the carrier as a single unit.
- Optimized tank orientation to maximize Orbiter fluid positioning potential using drag.
- A storage tank size and shape that maximizes scaling potential, as well as time constraints imposed by the orbiter mission to accomplish the defined objectives while not imposing weight impacts on HH-M carrier use.
- Electronics boxes mounted to the top of the carrier were the most suitable thermal environment for operation is found.
- Use of only a portion of the HH-M weight and avionics capability so that other payload manifesting potential exists.
- Provisions for growth to accommodate a receiver tank and associated components for a fluid transfer and tank filling expansion.
- Maximized use of carrier and Orbiter standard services and accommodations.
- In bay and to space vents to accommodate experiment effluent needs.
- Single string with high design reliability for a simple cost effective approach.

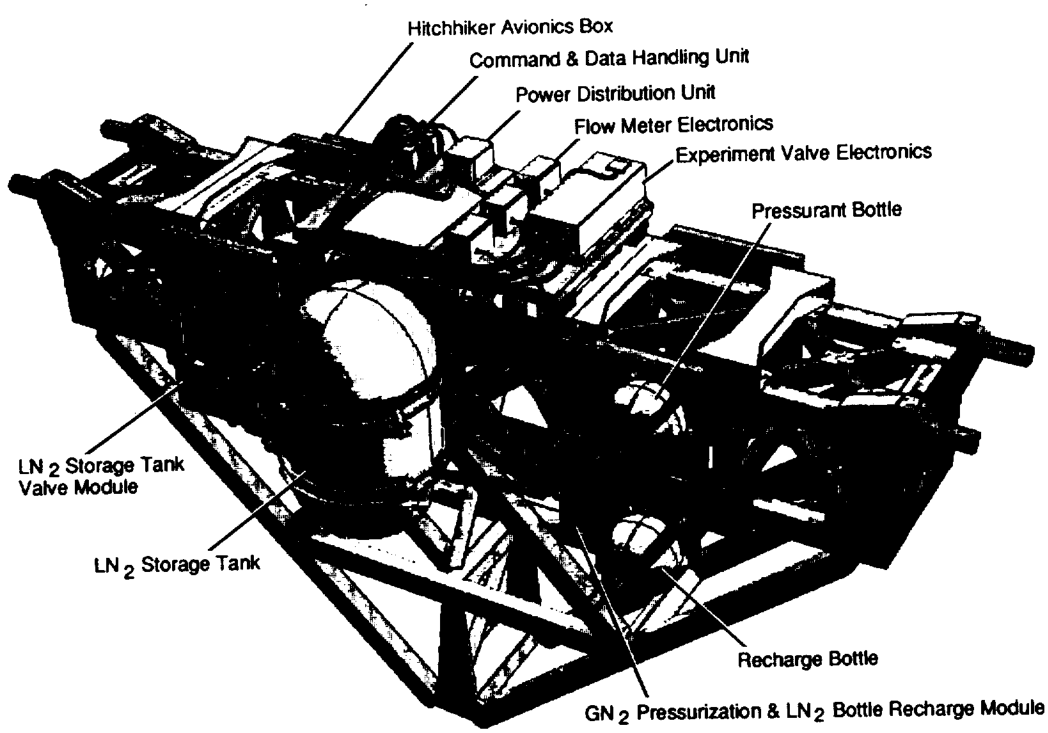


Figure 2.5-4 CONE Payload Mounted on the Hitchhiker-M Carrier

3.0 PAYLOAD REQUIREMENTS AND ALLOCATION

The need for advanced cryogenic fluid management technology for subcritical cryogens is driven by future space missions which will transport, store, and consume cryogenic fluids as part of their everyday mission operations. Various past activities have examined these needs and have categorized cryogenic technology requirements which demand in space testing under one or more of the following five major headings:

- Liquid Storage (thermal and pressure control)
- Liquid Supply (pressurization, acquisition and subcooling)
- Liquid Transfer (tank chilldown, fill or top-off)
- Fluid Handling (slosh and dumping)
- Advanced Instrumentation (mass gaging and flow metering)

Experiment requirements were provided in the CONE SOW and were iterated over the duration of the program to perform top-level testing mainly in liquid storage and liquid supply. Liquid transfer and fluid handling (dumping) were assessed for incorporation into the program. Funding constraints, however, did not allow for this activity to be formally worked. Enough effort was accomplished during a change proposal activity to gain confidence that such an approach for CONE is viable and cost effective. Secondary pressurization bottle recharging also falls in this liquid transfer category. Certain instrument assessments in flow metering and tank liquid level can be categorized under advanced instrumentation.

The technical objectives that form the science requirements for the CONE mission have been presented in an overview fashion in sections 1.0 and 2.0. They will be expanded upon in this section since they were the primary factor that led to the conceptualization and then baselining of a preliminary system design for the experiment subsystem and support subsystem elements that comprise the CONE payload. These science requirements drove the CONE system configuration and mission/operation definition.

<u>CONE Requirements Derivation Process</u> - The flow in Figure 3-1 defines the process for deriving and allocating CONE requirements so that a detailed conceptual design that meets the requirements was provided at the end of Subtask V.4 (Payload Preliminary Design). At the end of the initial requirements definition of Subtask V.2 and during the concept development of Subtask V.3 the system and experiment requirements have been derived and their allocation has been accomplished and has been iterated upon and concluded for the preliminary system design refinement of Subtask V.4. The principal features of this system engineering process include:

(1) Management visibility of all technical activities, tradeoffs, decisions, and design approaches to assure that cost and schedule criteria are met for all requirements.

(2) A top-down structured process is used to assure that detailed analysis, design, and development are continually consistent and compliant with requirements and allocations defined at all levels.

(3) Thorough analysis of requirements to assure completeness, accuracy, measurability, and traceability.

(4) Establishing information feedback and iteration loops during all phases of the concept syntheses and optimization development.

(5) Integration of all program functions throughout all phases of the system's concept development.

(6) Exercising management control using comprehensive reviews and through documentation of all requirements.

(7) Conducting continual system and interface compatibility analyses on evolving requirements and approaches to assure compliance with system requirements.

(8) Ensuring a continuing input of the safety issues into the requirements process.

This methodology was continued where required into the preliminary system design activity and will also become a part of follow-on detailed design, as well.

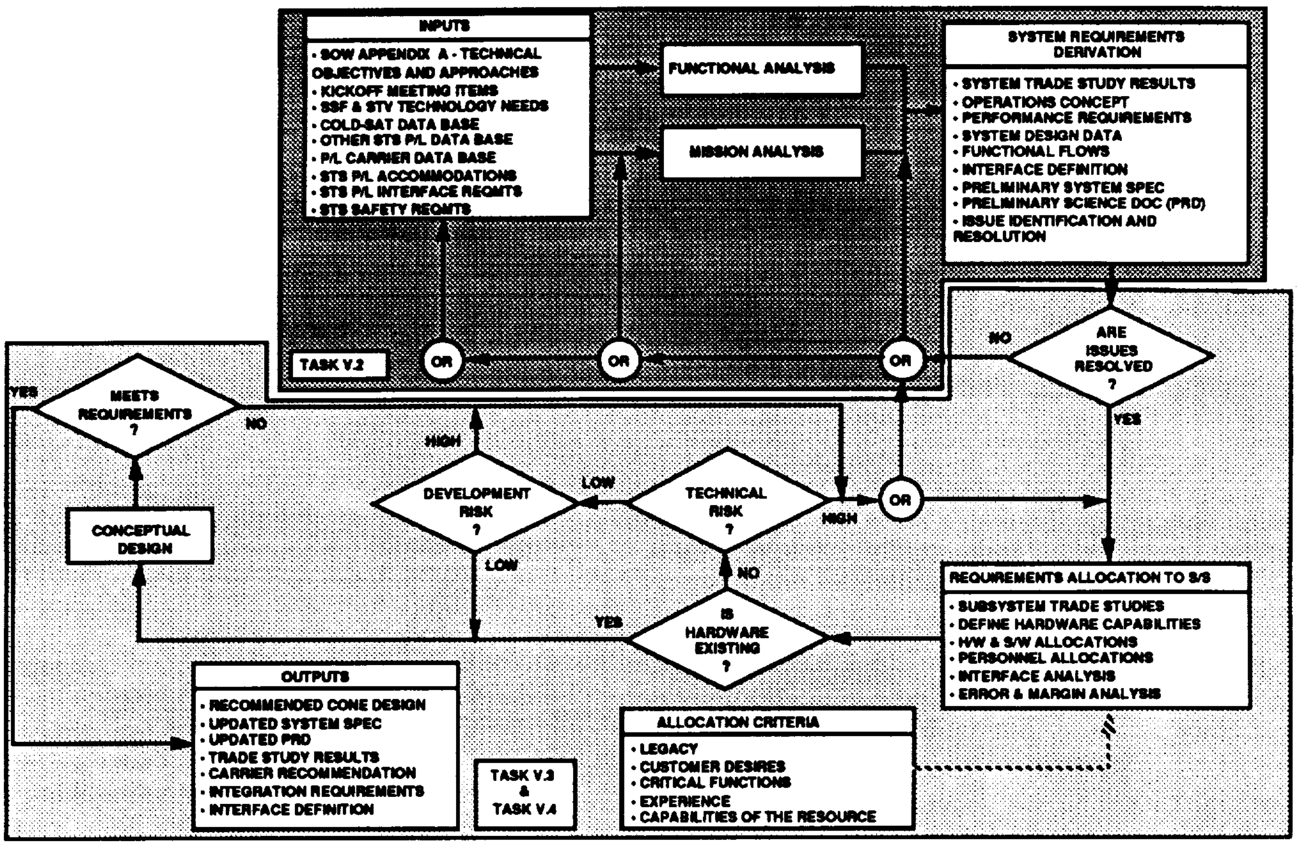


Figure 3-1 Requirements Derivation Process

The allocation between hardware and software depends primarily on passive hardware for safing, thus eliminating some redundancy requirements. The use of a distributed processing system with multiple processors for data processing, command processing, and network/sequence processing on a distributed network provides good reliability.

Requirements are allocated among hardware and software subsystems. Criteria were established to determine where and how requirements were allocated. For example, performance requirements are generally allocated to hardware. If an existing system satisfies similar requirements, new requirements are allocated in the same way. Allocation in a different way is used if a problem existed in the existing system. If LeRC has a strong preference about the allocation of particular requirements, the preference was observed if the solution was technically acceptable and consistent with other program considerations.

Any tasks too complex or important to be left totally to machines are allocated to people. In this case, the crew functions and power up initiation are examples. Some allocations were done in a certain way because they had worked that way in the past. Heritage plays a prime role in the allocation. Knowing the capabilities of the available or achievable hardware and software items is beneficial to any allocation effort. The basic input to the requirements allocation for CONE is the operations concept. Safety considerations predominate.

3.1 CFM Technology Goals

A brief summary of cryogenic fluid management technology goals for the five general categories is presented below. Fluid transfer and tank fill is included since it is strongly favored for eventual CONE incorporation and is a part of existing CONE recharge demonstrations. Fluid handling is included for completeness, but is not a technology area that CONE will be investigating.

Liquid Storage - Future applications require that cryogens be stored in space for periods of time ranging from several hours, to several days, to several years and involves minimizing liquid boil-off and controlling tank pressure. Various continuous storage scenarios for depots and Space Station Freedom needs have also been suggested. Cryogenic storage systems are dependant on effective thermal control system performance and tank pressure control to provide reasonable boil-off losses with passive thermodynamic vent system (TVS) control for long-term storage and active mixing for thermal stratification management for shorter duration needs. Some applications may require active refrigeration.

Heat reaches cryogenic tanks through the tank insulation, the support system, the plumbing penetrations, and through instrumentation lead wires. Heating rates are also strongly influenced by the external thermal environment and by any attempt to limit such heating by using thermal coatings and protections. While many of these influences can be well characterized, the performance of thick MLI blanket systems on large tankage with respect to heat transfer, attachment at the tank surface and reducing compression/maintaining adequate blanket density, as well as seam and closeout discontinuities, is difficult. All of these are issues which have to be addressed. They have implications associated with ground processing, ground servicing, launch environment, ascent effects and on-orbit influences. Other ground servicing factors for cryogen tanks that are loaded on the ground and then transported to orbit and which play an important part in this area include insulation options other than conventional vacuum-jacketed systems. These options might include application of closed-cell foam directly on the tank with MLI over the foam and having the entire system purged with dry nitrogen gas to preclude condensation of nitrogen or oxygen (if air were allowed to contact the tank). Requirements for a purge bag around the tank system is another complication that has to be considered.

Tank pressure control can be accomplished through proper tank thermal management utilizing one or more of the following:

1. Direct tank venting while the liquid is settled;
2. Using a thermodynamic vent system to both intercept and remove heat from the tank system, and/or;
3. Inhibiting/regulating thermal stratification by mixing the tank contents.

A TVS is termed a passive control system where sacrificial tank fluid is flashed through a throttling Joule-Thomson expander and then routed through internal tank heat exchangers and then into a heat exchanger on the vapor-cooled shield (VCS) that surrounds the tank. Active control is accomplished with circulation devices that mix the tank contents to provide quick, short term pressure control without regard for the heat energy management of the system. It is highly desirable to maintain the stored liquid at as low a pressure as possible to maximize the potential use of the fluid, and to minimize the weight of the tankage system. Optimization of these approaches and their efficient integration into tankage designs remains to be characterized. Finally, for very long-term storage applications, mechanical refrigerators could reduce venting losses by absorbing the majority of the heat input to the fluid storage tank.

Liquid Supply - This technology area will investigate the unproven process of feeding single-phase, vapor-free subcritical cryogenic liquid at a required and controlled thermodynamic state from a storage tank outlet to a user interface in the low-gravity space environment. The process involves the acquisition of tank fluid at the tank outlet using settling techniques or management of fluid using surface tension and capillary forces that make use of the characteristics of total communication fine mesh screen devices. Fluid expulsion is accomplished by autogenous gas pressurization. Expulsion using this technique also accounts for necessary subcooling effects that the liquid experiences as part of the process of going to a higher pressure condition. Heat exchangers can also be used to achieve desired levels of temperature reduction. Mechanically-pumped outflow can also be used where the pump ΔP provides both the driving force, as well as the required subcooling effect on the fluid. Proper inlet conditions have to be maintained at the pump inlet so as not to induce fluid vaporization. This can be accomplished by a slight pressurization of the tank or by heat exchanger fluid conditioning.

Fluid Handling [If Cryogenic Fluid Transfer is added] - In the technology area of fluid handling, various issues associated with fluid motion resulting from spacecraft maneuvering and its dynamic interaction with the spacecraft have to be better understood. The ambient, low-gravity, on-orbit environment will influence the static orientation of the liquid and accelerations produced by satellite operations, specifically those produced from maneuvers will cause liquid motion. The effect of the applied environments on the liquid motion, including such variables as tank size and shape, tank fill fraction, and presence of slosh baffling, are areas requiring on-orbit investigations so that safe and predictable spacecraft operations can be predicted. The forces on the tank wall resulting from the liquid motion influence the maneuvering of the spacecraft. Space missions which are aborted may require that the tank contents be rapidly dumped overboard. This process is not well understood. A dumping experiment will be performed if a receiver tank is added to the CONE approach.

Advanced Instrumentation - There is a recognized need in the area of advanced cryogenic instrumentation to develop devices that can perform the following:

- determine the quantity or mass of liquid in a tank under low-g conditions
- measure liquid and cold gas mass flow rates
- detect two phase flow (indicate when vapor is present)
- perform liquid level detection under settled low-g conditions where surface tension forces can still be dominant
- high accuracy thermometry ($\pm$ 0.1 K) and associated signal conditioning circuit design necessary to maintain this accuracy over a temperature change of 20-30 degrees.

An in-space cryogenic experiment will provide an ideal test bed for the evaluation of these devices.

Liquid Transfer [If Cryogenic Fluid Transfer Experiment is added] - This portion of the technology needs involves the requirement to transfer liquid from a supply tank to a receiver tank in the low-gravity space environment while minimizing liquid losses associated with the transfer process and controlling both the supply and specifically the receiver tank pressure during the chilldown and filling process. Low-g effects and the inability to readily vent the receiver tank during the filling process presents new problems that have to be overcome. These issues are all related to low-g influences on heat transfer rates and fluid motion/positioning.

The first step in the procedure is to chilldown the transfer line interconnecting the supply and receiver tank and then to chilldown the receiver tank while optimizing the amount of fluid consumed. The time required to accomplish these operations is also very dependant on low-g phenomenon and the amount of extra fluid available to be used to reduce the chilldown time. Tank chilldown can be performed using a direct contact wall-mounted heat exchanger through which chilldown fluid is routed on the tank wall, or by a charge-hold-vent technique whereby a fixed liquid charge is introduced into the tank via the spray systems. For the latter, the charge is held in the tank, allowing the transfer of heat from the tank wall to the fluid to take place until all of the fluid is vaporized. The fluid in the charge-hold-vent chilldown technique is ideally allowed enough time to come into thermal equilibrium with the tank wall. In reality, the fluid is allowed to nearly achieve the tank wall temperature since the heating time becomes substantial. The warm vapor is then vented to space and the process is repeated until the desired initial temperature for tank filling is reached. This entire process is dependant upon several heat transfer processes which are all operating under the unknown low-g influence. These heat transfer properties are expected to be also highly influenced by the fluid properties, liquid injection technique, tank wall temperature and tank size/shape.

The process of filling the receiver tank after chilldown from an initially empty configuration can be accomplished using the following approaches:

- no-vent fill
- vented fill
- ullage exchange

Variations in the above techniques can also be used to top-off a partially full tank.

It is highly desirable to accomplish resupply of user tanks without venting as the transfer proceeds, since establishing an acceleration environment to settle liquid and clear a vent port may significantly impact the user system. Many systems are very sensitive to proximity venting and in certain cases may not be allowed or are severely restricted. The no-vent fill process accomplishes the tank filling without venting and can be divided into the following three phases. The first phase starts at the beginning of the transfer and proceeds until liquid starts to accumulate. It is characterized by vaporization and flashing of incoming liquid. Phase-two covers most of the remaining fill process, where incoming liquid causes compression of the vapor. The final phase occurs throughout the fill process but is most important near the end of the process and involves condensation of vapor to make room for more liquid before vapor compression stops the process. It becomes very important to "find" the ullage with fine liquid sprays to maximize the fill level. The no-vent fill process involves the various heat transfer processes operating in the unknown effects of the low-g environment. These processes have to be investigated.

The vented-fill technique can be used if both venting and a settling acceleration environment can be created. Liquid is introduced into the tank via the outlet to try to allow the liquid to accumulate in this area as determined by fluid momentum and tank acceleration levels. When the tank pressure equals the saturated condition of the incoming fluid the tank vent can be opened to vent vapor and maintain the tank slightly above this condition. The settling acceleration will hopefully maintain a stable interface and allow only vapor to be vented as the tank fills. If fluid momentum is greater than a critical level, the incoming fluid will likely penetrate the fluid interface, resulting in geysering and probable liquid flow out the vent. When this occurs, the vent will be closed and the process terminated if a stable interface cannot be re-established. Venting prematurely can adversely effect the process by causing flashing and liquid carryover out the vent. Again, various unknown fluid and gravity effects are working and an understanding of the effects cannot be confidently predicted.

The last transfer technique, ullage exchange, is a form of a no-vent fill. The ullage exchange technique is a method of transferring liquids in a low-g environment which eliminates problems associated with vented or no-vent fill processes (but introduces other uncertainties). Fluid transfer with the ullage exchange technique is accomplished by connecting the supply and receiver tank fill and vent lines to each other so that there is a closed fluid loop connecting the two tanks. The supply tank has a liquid acquisition device (LAD) to deliver liquid to the tank outlet. The liquid is transferred to the receiver tank with a liquid pump. Pressure is relieved in the receiver tank as the tank is being filled by venting through the vent line. The position of the ullage is uncertain in such a process, so liquid or gas may be vented. All fluid vented from the receiver tank is collected in the supply tank. The ullage exchange approach offers several design and operational advantages over other techniques such as the no-vent fill approach, including a less complex receiver tank configuration, the capability to handle a non-condensible pressurant, and greater flexibility in performing receiver tank top-offs. The unknown technology issue is the capability of the process to sweep out ullage from the receiver tank so that significant ullage does not become trapped and thereby limit the fill level that can be obtained by the process. Investigating the ullage exchange process for tank fill is not envisioned for CONE.

Inherent in all of the above liquid transfer processes is the added complication of insuring that if the receiver tank contains a liquid acquisition device (LAD) that it is properly and completely filled during the tank filling process, and particularly for the initially empty case. For a tank top-off, it is also critical that the top-off process does not violate or compromise the integrity of the fluid in the LAD.

3.2 CONE Baseline Experiment Set Requirements

This section provides a narrative description of the payload baseline set of technical objectives. Details of the technical objectives and suggested experimental approach for the Cryogenic Orbital Nitrogen Experiment (CONE) will also be defined. Both demonstration and experiment technical objectives have been baselined which support very specific technologies relating to Space Station Freedom (SSF) and various classes of earth and space based Space Transfer Vehicles (STV). The objectives of the flight experiment are to collectively demonstrate the critical components and technologies required for on-orbit subcritical cryogenic fluid storage and supply, with a focus on pressure control techniques in a low-g environment and forms the highest priority of technology objectives. Both passive TVS and active mixing concepts of pressure control will be addressed from demonstration and experimentation viewpoints. The performance of an autogenous pressurization system and a capillary surface tension liquid acquisition device will also be evaluated. Originally tank mass gaging was included as a technical object. This requirement was later dropped due to the termination of further mass gage work by JSC and the lack of development of a suitable approach.

3.2.1 System Demonstrations

Space Station Freedom Cryogen Resupply System Demonstrations - These demonstrations will provide needed data to determine if Space Station consumables (N2 and O2) can be stored and outflowed in a subcritical state. Resupply of gaseous pressurant bottles where the commodities can be readily available for use on the Space Station using a liquid recharging technique will also be assessed. The unrelated issue of LAD performance and expulsion efficiency under nominal outflow conditions will also be evaluated as a demonstration.

Cryogenic Liquid Storage - Tank pressure control is accomplished through proper tank thermal management which for this application will investigate the use of a thermodynamic vent system to both intercept and remove heat from the tank system. Only tank pressure control using a LAD mounted TVS heat exchanger will be addressed by this demonstration and will characterize performance for heat fluxes for both vacuum jacketed and foam/MLI insulated cryogen storage systems. A TVS is termed a passive control system where sacrificial tank fluid is flashed through a throttling Joule-Thomson expander and then routed through internal tank heat exchangers. It is highly desirable to maintain the stored liquid at as low a pressure as possible to maximize the potential use of the fluid, and to minimize the weight of the tankage system. Optimization of these approaches and their efficient integration into tankage designs remains to be characterized. Technological objectives are as follows: 1) Evaluate the ability of a passive thermodynamic vent system (TVS) to maintain constant tank pressure using heat exchanger mounter to the internal liquid acquisition device or externally to the wall of the pressure vessel; 2) Compare experimentally determined vent rates with analytical performance predictions for various heat fluxes that are typical for both vacuum jacketed and foam/MLI insulated storage systems;

3) Operate the TVS at different levels of tank fill volume; and 4) Operate TVS at varying acceleration conditions.

An integrated subcritical cryogenic storage tank holding a suitable quantity of LN2 is needed to assess the pressure control aspects of a passive Thermodynamic Vent System (TVS) heat exchanger to remove heat from the system by controlled venting of the tank contents. Analytical models can predict tank heat leak, TVS flowrate, TVS heat exchanger size, TVS flow characterization, insulation characterization and tank pressure changes due to these effects. Four TVS tests are planned, two at each fill level. Long test duration (10-16 hr) limit the testing that can be accomplished.

A flow chart defining the tank TVS passive pressure control process is provided in Figure 3.2.1-1 along with a summary of the liquid storage demonstration objectives, principal requirements and derived requirements.

Future applications require that cryogens be stored in space for periods of time ranging from several hours, to several days, to several years and involves minimizing liquid boil-off and controlling tank pressure. Various continuous storage scenarios for depots and Space Station Freedom needs have also been suggested. Cryogenic storage systems are dependant on effective thermal control system performance and tank pressure control to provide reasonable boil-off losses with passive thermodynamic vent system (TVS) control for long-term storage.

The pressure in a cryogenic tank will rise if thermal energy is added to the tank and the tank is not vented. It is desirable to vent gas from a tank to minimize the mass of vented fluid. In an environment with a relatively large acceleration field, such as on the Earth's surface or on a thrusting rocket, the position of the ullage is known and gas can be easily vented. In a low-g environment, however, the position of the ullage may not be known and it may be impossible to vent gas directly from the tank. This difficulty can be overcome with a Thermodynamic Vent System (TVS). A TVS takes advantage of the fact that it is possible to position or locate liquid in in a low-g environment so that liquid can usually be withdrawn from the tank when it may be impossible to withdraw gas. A TVS functions by using liquid withdrawn from the tank and passing the liquid through a Joule-Thomson (J-T) expander. The J-T expander causes flashing of the liquid, which reduces the liquid's pressure and temperature. The two-phase fluid downstream of the J-T expander is routed through a heat exchanger in contact with the bulk liquid. Since the bulk liquid is warmer than the two-phase fluid, heat is transferred from the bulk liquid to the two-phase fluid. Heat transfer causes boiling in the two-phase side, and boiling continues until all liquid has evaporated. The gas may then be vented overboard. The J-T expander, heat exchanger, and control components comprise the TVS. TVS venting is similar to direct venting of the ullage, with the exception that the pressure of the vented TVS gas is lower. Thus, a TVS permits venting gas from a tank in an environment where it is easier to find liquid than gas in the tank. Passive pressure control refers in this case to the use of an internal LAD mounted TVS heat exchanger to control tank pressure. The thermal performance of a passive TVS is controlled by free or forced convection heat transfer in the bulk fluid and two-phase heat transfer in the TVS.

Liquid Nitrogen Supply - This technology area will investigate the unproven process of feeding single-phase, vapor-free subcritical cryogenic liquid at a required and controlled thermodynamic state from a storage tank outlet to a user interface in the low-gravity space environment. The process involves the acquisition of tank fluid at the tank outlet by the management of fluid using surface tension and capillary forces that make use of the characteristics of total communication fine mesh screen devices. Fluid expulsion is accomplished by autogenous gas pressurization using gaseous nitrogen (GN2). Expulsion using a pressurization technique also accounts for necessary subcooling effects that the liquid experiences as part of the process of going to a higher pressure condition. Heat exchangers can also be used to achieve desired levels of temperature reduction/subcooling. Technological objectives include:

CRYOGENIC LIQUID STORAGE DEMONSTRATION OBJECTIVES & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - EVALUATE ABILITY OF PASSIVE TVS TO MAINTAIN CONSTANT TANK PRESSURE USING LAD OR WALL MOUNTED HEAT EXCHANGERS
- FUNCTIONAL REQUIREMENT
  - COMPARE EXPERIMENTALLY DETERMINED VENT RATES WITH ANALYTICAL PERFORMANCE PREDICTIONS FOR VARIOUS HEAT FLUXES
    1) TYPICAL FOR VACUUM JACKETED STORAGE SYSTEM
    2) TYPICAL FOR FOAM/MLI INSULATED STORAGE SYSTEM
  - OPERATE TVS AT SEVERAL FILL VOLUMES
  - OPERATE TVS AT RANDOM ACCELERATION CONDITIONS
- PARAMETERS BEING VARIED
  - HEAT FLUX INTO THE TANK
  - ACCELERATION ENVIRONMENT (UNCONTROLLED & VARYING)
  - TANK LIQUID LEVEL (UNCONTROLLED AND NON-REPEATABLE)
  - TVS FLOW ON/OFF
- KEY MEASUREMENTS REQUIRED
  - TANK TEMPERATURE (BOTH WALL AND FLUID)
  - TANK PRESSURE (INCREASE & DECREASE)
  - ACCELERATION ENVIRONMENT
  - TVS OUTFLOW RATE
  - TANK HEATER POWER

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
LIQUID FILL LEVELS	80% 40%	STORAGE TANK	LOWEST INITIAL FILL LEVEL FILL LEVEL AFTER OUTFLOW AND RECHARGE	EA-CONE-007 TD
HEAT FLUXES	0.45 BTU/FT^2-HR 0.90 BTU/FT^2-HR	STORAGE TANK HEATERS	TYPICAL MLI PERFORMANCE 2 X TYPICAL PERFORMANCE (W/ HEATER)	TD
FLOW RATES	0.30 LBM/HR	TVS	HIGH HEAT J-T EXPANDER LIMITATIONS	EA-CONE-021A EA-CONE-031
NUMBER OF TESTS	4	SOFTWARE	ORTHOGONAL MATRIX: 2 FILL LEVELS X 2 HEAT RATES	EA-CONE-020
TEST DURATIONS	#1 - 14 HRS #2 - 16 HRS #3 - 14 HRS #4 - 16 HRS	SOFTWARE	TEST SEQUENCING	EA-CONE-021A
PRESS. CONTROL DEAD BAND	0.10 PSI	SOFTWARE	REDUCE TEST DURATION	EA-CONE-021A
TVS HEAT EXCHANGER CONFIGURATION	LAD MOUNTED CONTINUOUS	TVS	EASE OF MANUFACTURE PROVIDE UNIFORM COOLING	EA-CONE-021A
TVS SIZING	DRY OUT BEFORE LEAVING TANK AT HIGH FLOW	TVS	EFFICIENT UTILIZATION OF TVS FLUID	EA-CONE-021A

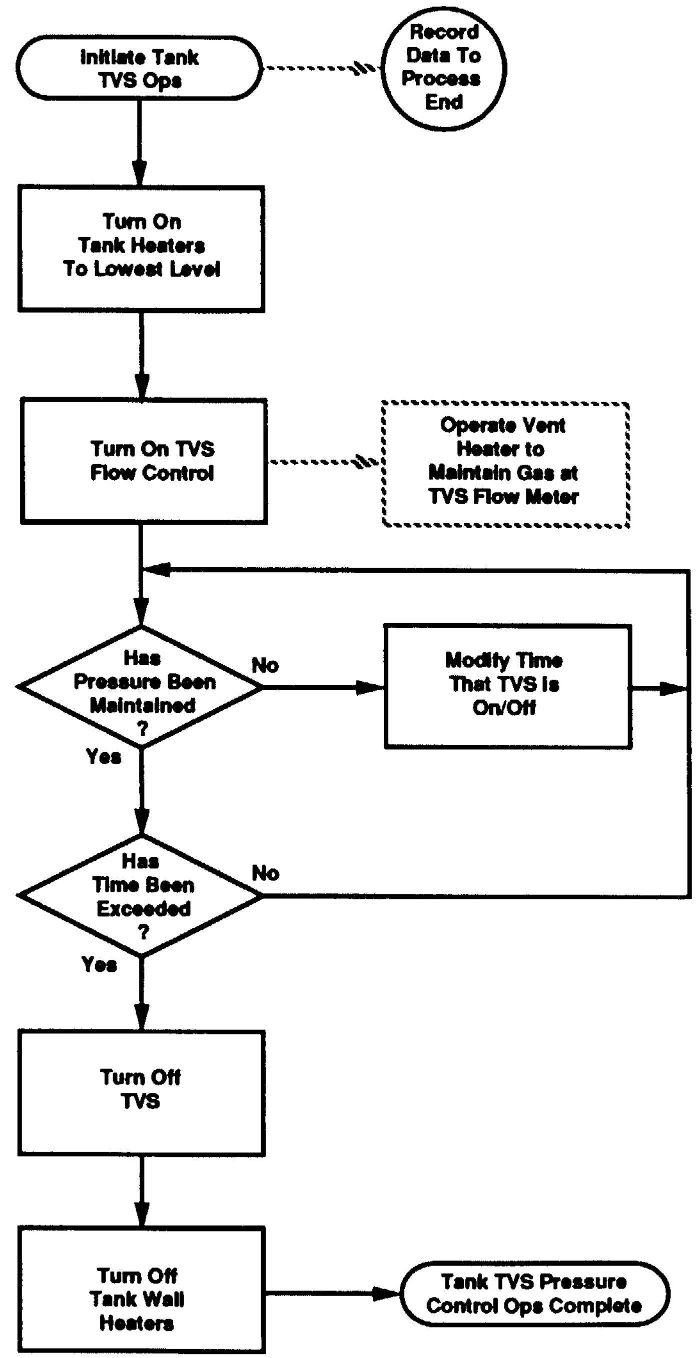


Figure 3.2.1-1 Tank TVS Passive Pressure Control Operation Requirements and Process Flow Chart

1) Demonstrate the ability to supply subcooled liquid nitrogen in a low-gravity environment to a simulated user by employing a total communication fine mesh screen capillary device for liquid acquisition. This objective will accomplish the pressurant bottle recharge function for the third CONE demonstration.
2) Use gaseous nitrogen for liquid expulsion and compare rates of pressurant consumption with analytical predictions for two discrete values of liquid subcooling and two discrete values of liquid expulsion rate. Varying pressure levels will account for the different liquid expulsion rates obtained and/or the discrete levels of liquid subcooling.
3) Performance of an advanced technology mass flow meter will also be assessed, if available.

Tests in this area all relate to the process of expelling LN2 from the storage and supply tank, maintaining proper liquid quality during the expulsion and providing the proper gaseous pressurant needed as the driving force to expel the liquid to a simulated user, which in this case is to the space environment for most of the tests. A small portion of the tank outflows will be directed towards chilldown of a depleted pressurant tank and subsequent introduction of a small no-vent fill of fluid to the tank to support the next technology task (pressurant bottle recharging). In order to provide vapor free liquid which can be maintained as liquid in the outflow line, a total communication capillary surface tension liquid acquisition device (LAD) is required in the storage and supply tank. The capability of the LAD to perform this function for different tank fill levels, as well as two discrete values of liquid subcooling, will be assessed providing suitable instrumentation can be developed for two phase flow detection. Analytical models required to predict the behavior of the GN2 pressurization and tank LN2 outflow process provide determinations of quantities of GN2 gas required for pressurization. Quantities used are based on tank fill conditions, GN2 required to maintain tank outflow at a given flow rate, expected subcooling of the fluid leaving the tank, expected fluid condition at the user interface, and conditions at the tank liquid/vapor interface during pressurization. Two outflows are planned, one to change the fluid level from high to low and a final outflow to LAD depletion.

A flow chart defining the tank outflow process is provided in Figure 3.2.1-2 along with a summary of the liquid outflow demonstration objectives, principal requirements and derived requirements.

The ability of a liquid acquisition device (LAD) to deliver vapor-free liquid in a low-g environment highly depends on the extent that vapor can penetrate the LAD screen. Vapor penetration is resisted by liquid wetting of the screen and by the maximum differential pressure which can be resisted through the screen, or the bubble point pressure difference. The pressure difference across the screen is caused by flow losses through the screen and channels, hydrostatic head, hydraulic transients, external vibrations or dynamic loading. The total sum of these individual components to the pressure loss must not exceed the screen bubble point in order to preclude vapor ingestion with consequential screen breakdown. Also, the total pressure difference must not exceed the extent of the liquid subcooling or the liquid will flash and vaporize, thus introducing vapor into the channel as well. This is particularly important where liquid may be stored near its saturation condition.

Different thermodynamic conditions of the liquid nitrogen in the CONE storage tank as well as imposing different flow conditions will be investigated on the performance of liquid expulsion in the storage tank. The determination of the conditions under which the LAD in the CONE storage tank will provide vapor-free liquid are the important physical processes to be studied. This demonstration will be performed as a series of outflows designed to study the fluid processes associated with acquiring liquid nitrogen using a total communication capillary liquid acquisition device for outflow and transfer in a low gravity acceleration environment. The process by which vapor-free liquid expulsion is obtained is important in studying what parameters affect liquid acquisition performance for effective liquid transfer to users. These tests will examine the effects on the acquisition and outflow of liquid nitrogen to possible users such as the Space Station Freedom and STV/Depot tank concepts using capillary fine mesh screen LAD's. The processes to be studied include liquid outflow in low-gravity for a variety of liquid subcooling and flow rate conditions. Such phenomena as vapor ingestion, LAD

LN2 SUPPLY SYSTEM DEMONSTRATION OBJECTIVES
& PRINCIPAL REQUIREMENTS

- OBJECTIVE

  - DEMONSTRATE THE ABILITY TO SUPPLY SUBCOOLED LIQUID NITROGEN TO A SIMULATED USER AT

    1) TWO DISCRETE VALUES OF SUBCOOLING
    2) TWO DISCRETE VALUES OF LIQUID EXPULSION RATE

- FUNCTIONAL REQUIREMENT

  - EMPLOY A TOTAL COMMUNICATION FINE MESH SCREEN CAPILLARY DEVICE FOR LIQUID ACQUISITION
  - HIGH PRESSURE GASEOUS NITROGEN FOR LIQUID EXPULSION
  - COMPARE RATES OF PRESSURANT CONSUMPTION WITH ANALYTICAL PREDICTIONS

- PARAMETERS BEING VARIED

  - ACCELERATION ENVIRONMENT (UNCONTROLLED AND VARYING)
  - OUTFLOW RATE
  - TANK LIQUID LEVEL
  - OUTFLOW SUBCOOLING RATE

- KEY MEASUREMENTS REQUIRED

  - ACCELERATION ENVIRONMENT
  - OUTFLOW LINE FLOW RATE
  - TANK PRESSURE
  - OUTFLOW LIQUID TEMPERATURE
  - TANK FLUID QUANTITY
  - GN2 PRESSURANT PRESSURE
  - OHX FLOW RATE

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
FLOW RATES	500 LBM/HR 100 LBM/HR	FLOW CONTROL ORIFICES	REPRESENTITIVE DEPOT F.R. BOTTLE RECHARGE F.R.	TD EA-CONE-002A
PRESS LEVEL	10 PSID OVER NOMINAL	PRES. SUB-SYS.	ADEQUATE ΔP FOR TANK RECHARGE	EA-CONE-025
PRESSURANT QUANTITY	13 LBM	PRES. SUB-SYS.	8.2 LBM CALCULATED MASS + MARGIN, EXISTING TANK	EA-CONE-018A
SUBCOOLING LEVELS	10 PSID 20 PSID	OHX	10 ΔP PRESS., NO OHX 10 ΔP PRESS., 10 PSID OHX	EA-CONE-032
OHX FLOWRATES	9 LBM/HR 0 LBM/HR	OHX	COMMONALITY WITH CHX FLOW CONTROL NO THERMAL SUBCOOLING	EA-CONE-015A
NUMBER OF TESTS	2	SOFTWARE	MINIMUM NUMBER REQUIRED FOR DEMONSTRATION	EA-CONE--020
LN2 HIGH FLOW DISPOSAL	VENT AWAY FROM ORBITER	VENT	PREVENT LN2 IMPINGING ON ORBITER	NHB-1700.7

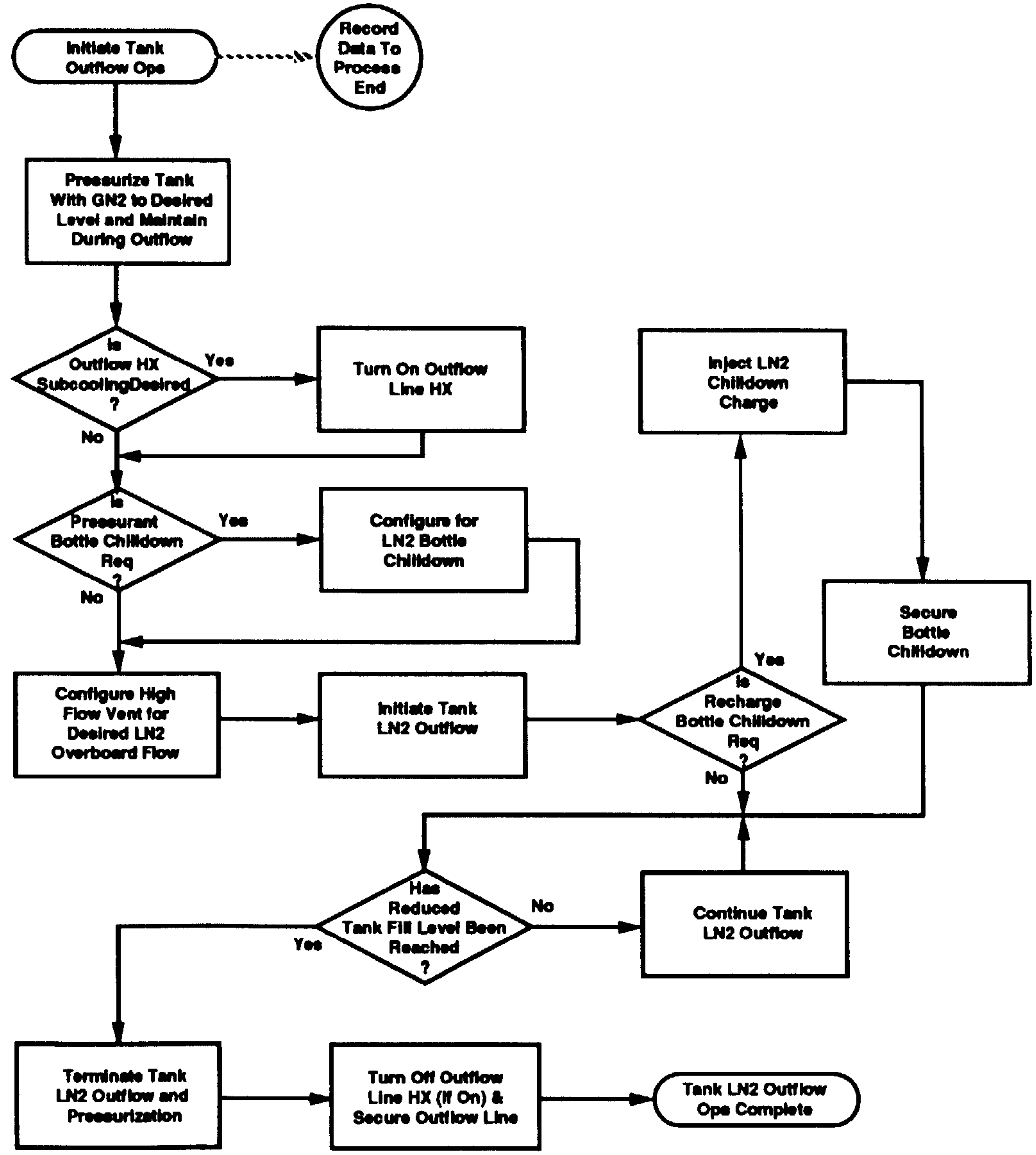


Figure 3.2.1-2 Tank Liquid Operation Requirements and Outflow Process Flow Chart

breakdown, and quality of liquid expelled will be examined to characterize the liquid supply (expulsion) process. Moreover, the liquid nitrogen supply tests will be accomplished to provide the initial conditions for conducting the other CONE demonstrations and experiments at various fill level conditions.

Pressurant Bottle Recharging - This portion of the technology needs involves the requirement to transfer liquid from a supply tank to a depleted pressurant tank in the low-gravity space environment while minimizing liquid losses associated with the transfer process and controlling both the supply and the pressurant tank pressure during the chilldown, filling and associated warm-up process. It is highly desirable to accomplish resupply of gaseous pressurant tank using liquid so that economies associated with such recharging can be realized.

The no-vent fill process accomplishes the tank filling without venting and can be divided into the following three phases. The first phase starts at the beginning of the transfer and proceeds until liquid starts to accumulate and is initiated into a locked-up tank that has previously been chilled down and evacuated to space. It is characterized by vaporization and flashing of incoming liquid. Phase-two covers most of the remaining fill process were incoming liquid causes compression of the vapor. The final phase occurs throughout the fill process but is most important near the end of the process and involves condensation of vapor to make room for more liquid before vapor compression stops the process. This last phase is not critical to this demonstration since a complete fill is not required. More important to this bottle recharging test is proper metering of fluid to the bottle so as not to create an over pressure condition after warm-up. Technological objectives are as follows: 1) Chilldown pressurant bottle to a "target temperature"; 2) Evacuate to space and close the vent; 3) Inject a metered quantity of liquid nitrogen; 4) Self pressurize by environmental heating and 5) Compare final warm-up pressure with analytical predictions.

On-orbit investigation of the ability to recharge depleted pressurant bottles using liquid instead of gas will be demonstrated. This will simplify the gas resupply process and possibly reduce the number of bottles in a pressurization system by using available liquid. Using one of the depleted high pressure pressurant bottles of the pressurization system, a demonstration will be performed to recharge the depleted bottle. Two recharge tests will be performed, one with a chilldown and one without.

A flow chart defining the bottle recharge process is provided in Figure 3.2.1-3 along with a summary of the bottle recharge demonstration objectives, principal requirements and derived requirements.

The first step in the procedure is to chilldown the tank outflow line interconnecting the supply and pressurant tank and then to chilldown the pressurant tank while keeping tract of the amount of fluid consumed. The time required to accomplish these operations is also very dependant on low-g phenomenon and the amount of extra fluid available to be used to reduce the chilldown time. For this process the amount of fluid to perform the tank chilldown will amount to the fluid quantity to complete a single chilldown cycle. The pressurant bottle recharge will be accomplished by the injection of a known amount of fluid into the tank. This task will chill the tank and then flow enough liquid into the tank to achieve the final required tank pressure. The tank may be chilled by the initial charge, that is the initial wall temperature for the fill may be as high as ambient and requires a high flow rate to inject enough fluid to accommodate complete pressurization. It is more likely though that the tank will require some chilling so that the liquid flow rate can be maintained at a lower flow rate. This initial chill will be achieved by a single charge-hold-vent cycle and results in the minimal chilldown fluid consumed. Once the bottle has been chilled down , the recharge injection will be performed. This process consists simply of filling the tank with a cryogen without venting any of the liquid that will boil off. The recharge injection does not have to approach an optimal case, since the final fill is the difficult part of the fill and the required final fill level of the bottle will only be ~ 30%. This relaxation allows the fill to proceed due to inflow alone, that is the complexity of mixing nozzles will not be required. A second recharge will be performed without chilling the bottle wall and will use a much higher flow rate to inject sufficient liquid for complete bottle pressurization.

PRESSURANT BOTTLE RECHARGING DEMONSTRATION
OBJECTIVES & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - RESUPPLY GASEOUS NITROGEN PRESSURANT BOTTLE
- FUNCTIONAL REQUIREMENT
  - CHILL PRESSURANT BOTTLE TO "TARGET TEMPERATURE"
  - EVACUATE TO SPACE AND CLOSE VENT
  - NO-VENT FILL WITH METERED QUANTITY OF LIQUID NITROGEN
  - SELF-PRESSURIZE BY ENVIRONMENTAL HEATING
  - COMPARE FINAL PRESSURE WITH ANALYTICAL PREDICTIONS
- PARAMETERS BEING VARIED
  - INITIAL WALL TEMPERATURE
  - LN2 INJECTION FLOW RATE
- KEY MEASUREMENTS REQUIRED
  - BOTTLE TEMPERATURE
  - BOTTLE PRESSURE CHANGE DURING CHILLDOWN, FILL AND WARM-UP
  - LN2 MASS USED FOR CHILLDOWN
  - LN2 MASS INJECTED

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
RECHARGE BOTTLE	FANSTEEL P/N 4425068 (CFME)	PRESSURANT TANKS	ALL METAL TANK SIMPLIFIES ANALYSIS & EASIER TO QUALIFY LeRC HAS 4 TANKS WHICH COULD BE TESTED W/ IR&D	EA-CONE-022
NO VENT FILL FLOWRATE	1500 LBM/HR 500 LBM/HR	FLOW CONTROL ORIFICES	F. R. W/O CHILLDOWN F. R. FOR LAD EXP. EFF.	EA-CONE-019A TD
TARGET TEMP	250 °R	SOFTWARE	TARGET TEMPERATURE FOR 500 LBM/HR	EA-CONE-019A
CHILL DOWN METHOD	CHARGE-HOLD-VENT	SOFTWARE	DESIRABLE CHILLDOWN METHOD	EA-CONE-019A
NUMBER OF TESTS	2	SOFTWARE	SUFFICIENT TIME TO DO MULTIPLE TESTS	EA-CONE-019A TD
RECHARGE FILL LEVEL	30%	SOFTWARE	MASS REQD. TO PRESSURIZE TANK TO 3000 PSI @ BAY TEMP	EA-CONE-019A
SURF. EMISSIVITY	0.86	PRES. TANKS	DESIRABLE SURFACE	EA-CONE-019A

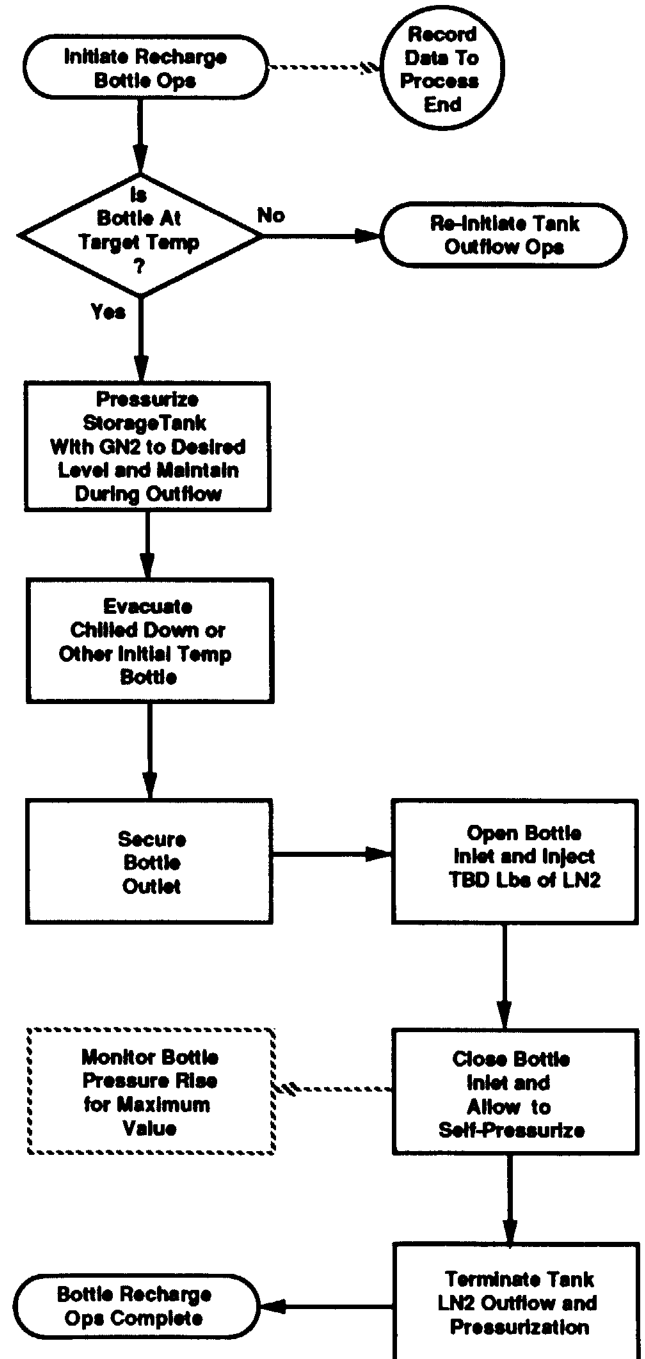


Figure 3.2.1-3 Pressurant Bottle Recharge Operation Requirements and Process Flow Chart

Liquid Acquisition Device Performance (Expulsion Efficiency) - This demonstration is to determine how much liquid can be removed from the LN2 storage tank before the LAD breaks down due to loss of capillary retention capability caused by lack of fluid to wet the screen. Such a condition will allow vapor to flow into the outlet line and results in the inability to use remaining fluid in a vapor free form. The remaining tank fluid when this occurs is a residual, the percentage of which is expressed as the efficiency to deplete the tank contents. This quantity can be determined analytically using modeling techniques. The quantity can be compared to actual values for a nominal outflow condition where tank fluid is drained from the outlet until screen breakdown occurs. Acquisition device channel cross-sections are a function of the flowrate requirements and the expected acceleration environment in which the device is expected to operate for a particular mission. Sizing involves the determination of screen breakdown for each use situation where working media and tank size must be considered. Technological objectives include: 1) Determine the quantity of vapor-free liquid that can be removed from the storage tank using a total communication fine mesh screen LAD with symmetric channels that are being depleted in a uniform manner; 2) Compare the amount of liquid residuals with analytical predictions to understand the phenomena that contribute to LAD expulsion efficiency.

A flow chart defining the storage tank LAD performance expulsion efficiency process is provided in Figure 3.2.1-4 along with a summary of the tank expulsion demonstration objectives, principal requirements and derived requirements.

Basically, the physical processes to be studied and the analytical models used are a subset of those required for the Liquid Nitrogen Supply Demonstration as it applies to a near complete tank expulsion and the resulting expulsion efficiency possible with a fine mesh screen device. The physical processes to be studied from the Liquid Acquisition Device Performance Experiment involve the fluid phenomena associated with capillary acquisition, screen flow, channel flow, and hydrostatic pressure head. Collectively, from a fluid dynamic standpoint, these phenomena contribute to a total screen differential pressure that either allows the screen device to hold liquid or that allows vapor to pass through the screen structure in a liquid acquisition and flow situation. When the pressure change (drop) in the screen device becomes greater than the surface tension forces that wick the fluid to the screen, then the pressure differential across the screen will tend to force vapor through the screen and into the channel, usually resulting in LAD dryout and an inability to function as a capillary device.

The liquid acquisition device (LAD) is the key element for the supply of liquid cryogen. Because the orientation of the liquid in the low-g environment tends to be arbitrary, a concept that can maintain communication with the liquid regardless of its location is required. This device provides the means of expelling gas-free liquid from a storage tank in the low-g operational environment by making use of the surface tension forces of the liquid in consonance with characteristics of fine mesh screens. Flow channels that encircle the interior of the tank in contact with the tank wall are faced with this fine mesh screen. These channels manifold to provide a flow path between the liquid in its low-g orientation and the tank outlet.

3.2.2 Controlled Experiments

Technology Development by Controlled Experimentation - Certain critical technology areas require in-space, low-g subscale testing as a confidence enhancement prior to commitment to a more sophisticated experimentally-orientated type of approach. Technology areas associated with maintaining tank pressure control and reducing thermal stratification by actively mixing the tank contents will be addressed. The unrelated issue of LAD performance and expulsion efficiency under nominal and off-nominal conditions will also be evaluated. These experiments will provide needed answers to assist the design of the STV and in-space cryogen depot storage systems, as well as providing data and analytical correlation of models which will serve to mitigate the level of uncertainty associated with more advanced and refined experiments which can address critical issues unobtainable in the Orbiter environment.

LAD EXPULSION EFFICIENCY EXPERIMENT OBJECTIVES & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - DETERMINE THE QUANTITY OF VAPOR FREE LIQUID THAT CAN BE REMOVED
- FUNCTIONAL REQUIREMENT
  - TOTAL COMMUNICATION FINE MESH SCREEN LAD
  - ACCELERATION TO STRESS LAD AT END OF EXPULSION
  - COMPARE AMOUNT OF LIQUID RESIDUALS WITH ANALYTICAL PREDICTIONS
- PARAMETERS BEING VARIED - NONE
- KEY MEASUREMENTS REQUIRED
  - OUTFLOW LINE FLOW METER QUALITY INDICATION
  - TANK OUTFLOW RATE
  - TANK FLUID TEMPERATURE
  - TANK PRESSURE
  - TANK RESIDUAL DETERMINATION (CHX FLOWRATE)
  - LIQUID SUBCOOLING LEVEL

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
FLOW RATE	500 LBM/HR	FLOW ORIFICES	STRESS LAD	EA-CONE-005B
FLOW DISTRIBUTION	UNIFORM	LAD	SIMPLIFY FLOW ANALYSIS	EA-CONE-014
LAD CONFIGURATION	3 CHANNELS	LAD	KEEP LAD SUBMERGED DURING LAUNCH	EA-CONE-014
	SYMMETRIC		UNIFORM FLOW	EA-CONE-014
	325 X 2300 SS SCREEN		HIGHEST LIQUID RETENTION CAPABILITY	
	OUTLET AT TOP		STRESS LAD	EA-CONE-005A
VALVE CLOSING RATE	RAPID	ISOLATION VALVE	TRAP RESIDUALS AFTER BREAKDOWN	EA-CONE-005A
MAXIMUM SYSTEM PRESSURE	100 PSIA	FLUID DISTRIBUTION	WORST CASE WATER HAMMER	EA-CONE-017

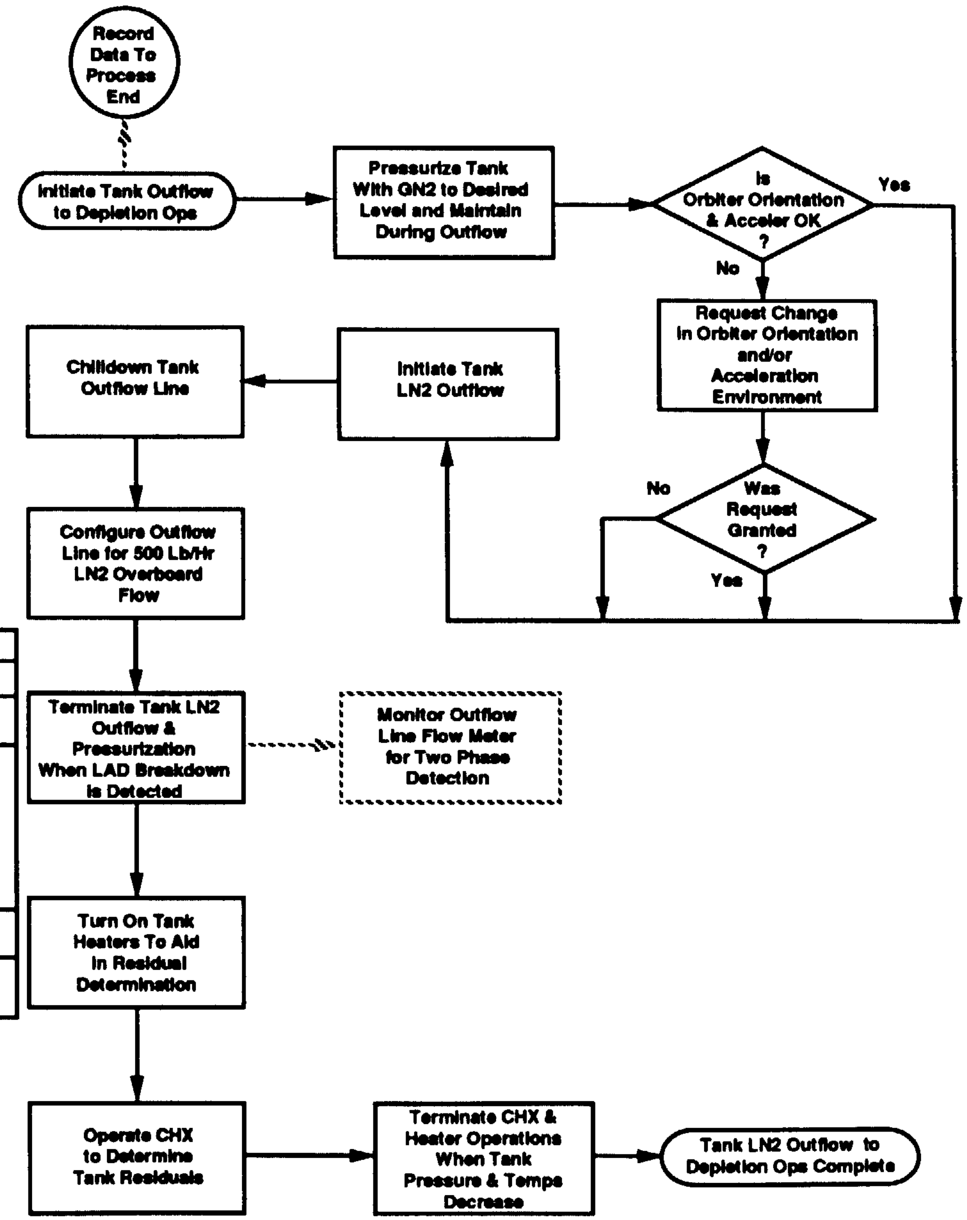


Figure 3.2.1-4 LAD Performance Expulsion Efficiency Operation Requirements and Process Flow Chart

Active Pressure Control - In this experiment, the capability to control tank pressure by active mixing of the tank contents coupled with tank heat removal with a compact heat exchanger will be assessed. The effect of the following variable parameters will be evaluated on 1) thermal stratification of the tank fluid contents, 2) thermal destratification of the tank fluid contents by axial-jet mixing, and 3) tank pressure decay during mixing/compact heat exchanger operation:

a. changes in tank heat flux up to 16 times that of ambient
b. changes in mixer flow rate from maximum to nominal
c. variations in heat exchanger flow rate which will remove up to 25 times the nominal heat leak for tank pressure control and reduction
d. differences in tank fill level from near empty to near full
e. variations in the acceleration environment depending on capabilities and negotiated usage with the NSTS Orbiter.

Active control is accomplished with circulation devices that mix the tank contents to provide quick, short term pressure control while also accounting for the heat energy management of the system by using a heat exchanger coupled to the mixing device. It is highly desirable to maintain the stored liquid at as low a pressure as possible to maximize the potential use of the fluid, and to minimize the weight of the tankage system. Optimization of these approaches and their efficient integration into tankage designs remains to be characterized.

Data from these experiments will be used to correlate analytical model predictions of the processes involved which include: amount of temperature variation within the tank, time intervals required to effect stratification and destratification and the tank pressure changes associated with each. Models to predict such behavior address all of these parametric needs. Four stratification, four mixing and eight compact heat exchanger experiments will be performed.

A flow chart defining the storage tank thermal stratification process is provided in Figure 3.2.2-1 along with a summary of the tank thermal stratification experiment objectives, principal requirements and derived requirements.

The pressure in a cryogenic tank will rise if thermal energy is added to the tank. The rate of pressurization is influenced by the rate of heat addition, the fill level of the tank, and the degree of thermal stratification in the tank. Thermal stratification is important because a warm liquid layer adjacent to the ullage will impose its vapor pressure on the ullage, thereby raising the tank pressure above its non-stratified value. Stratification occurs because warming a liquid usually lowers its density. In the presence of an acceleration field, warm liquid will move to the surface while colder liquid moves to the bottom of the tank, resulting in thermal stratification along the tank axis. Acceleration level is a significant parameter in the development of the thermal stratification because the movement of liquid is a buoyancy driven phenomenon. The expansion of the liquid also affects stratification by performing work on the ullage. Work raises the ullage temperature which increases the heat transfer rate to the liquid surface and directly warms the liquid surface. Localized heating of the ullage has the same effect. Acceleration level can influence direct ullage heating by affecting the shape of the liquid/vapor interface. In a low-g environment, the meniscus of a wetting liquid may completely surround the ullage, thereby preventing direct heating of the ullage from the tank wall. The magnitude of the wall heating rate influences thermal stratification by controlling the radial thermal stratification in the tank. If the heating rate is low, then there will be a small thermal gradient near the wall and little difference in liquid densities. Buoyancy will be diminished in this case. The formation of the warm liquid layer adjacent to the ullage as a consequence of these effects is the physical process to be studied in the stratification and pressure rise experiments.

The acceleration environment of the Shuttle presents a major constraint against the completion of a quiescent stratification test. Experience from other STS experiments has shown that the random acceleration from mechanical and human sources will be an order or two greater in magnitude than the

ACTIVE PRESSURE CONTROL EXPERIMENT OBJECTIVE & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - EVALUATE THE ABILITY TO CONTROL CRYOGENIC STORAGE TANK PRESSURE USING A JET-INDUCED MIXER COUPLED WITH A COMPACT HEAT EXCHANGER (CHX)
- FUNCTIONAL REQUIREMENT
  - INVESTIGATE THE EFFECTS OF TANK HEAT FLUX, AXIAL-JET FLOW RATE, CHX FLOW RATE, TANK FILL LEVEL AND ACCELERATION ON:
    1) THERMAL STRATIFICATION OF TEST FLUID
    2) THERMAL DESTRATIFICATION BY AXIAL-JET INDUCED MIXING
    3) PRESSURE DECAY DURING CHX OPERATION
  - COMPARE WITH ANALYTICAL MODEL PREDICTIONS
  - PARTIAL VERIFICATION OF ANALYTICAL MODELS
- PARAMETERS BEING VARIED
  - HEAT FLUX INTO THE TANK
  - ACCELERATION ENVIRONMENT
  - LIQUID FILL LEVEL (MASS GAGE)
  - MIXER FLOW RATE
  - CHX FLOW RATE
- KEY MEASUREMENTS REQUIRED
  - TANK TEMP (BOTH WALL AND FLUID)
  - TANK PRESSURE (INCREASE & DECREASE)
  - ACCELERATION ENVIRONMENT
  - LIQUID/VAPOR INTERFACE POSITION
  - CHX FLOW RATES
  - MIXER PUMP POWER

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
EFFECTS INVESTIGATED FOR STRATIFICATION	FILL LEVEL ACCELERATION	SOFTWARE ORBITER TANK HEATERS	PARAMETERS WHICH COULD AFFECT STRATIFICATION	TD
STRATIFICATION TESTS	4	SOFTWARE	ORTHOGONAL MATRIX - 2 FILL LEVELS X 2 ACC. LEVELS	EA-CONE-020
TANK ORIENTATION	PARALLEL TO Z AXIS	STORAGE TANK	PERMITS STABLE I/F IN HIGH DRAG MODE	EA-CONE-013
ORBITER ATTITUDES	UNSPECIFIED Z AXIS INTO VELOCITY VECTOR	ORBITER STORAGE TANK	UNSPECIFIED LIQUID POSITION MAINTAIN SETTLED LIQUID	TD TD
HEAT FLUXES	0.45 BTU/HR-FT^2 7.2 BTU/HR-FT^2	HEATERS SOFTWARE	NOMINAL Q RAYLEIGH # SCALING FOR STRATIFICATION TESTS	EA-CONE-024
MAXIMUM STRATIFICATION TIME	8 HOURS	SOFTWARE	PRESSURE RISE DURING SLEEP SHIFT	EA-CONE-024 EA-CONE-016
STRATIFICATION DURATIONS	5 HRS 2 HRS	SOFTWARE	5 PSI PRESSURE RISE, HOMOGENEOUS MODEL, 80% FULL 5 PSI PRESSURE RISE, HOMOGENEOUS MODEL, 40% FULL	EA-CONE-024
MAXIMUM TANK OPERATING PRESSURE	50 PSI	RELIEF VALVE BURST DISK	MAXIMUM PRESSURE RISE	EA-CONE-024

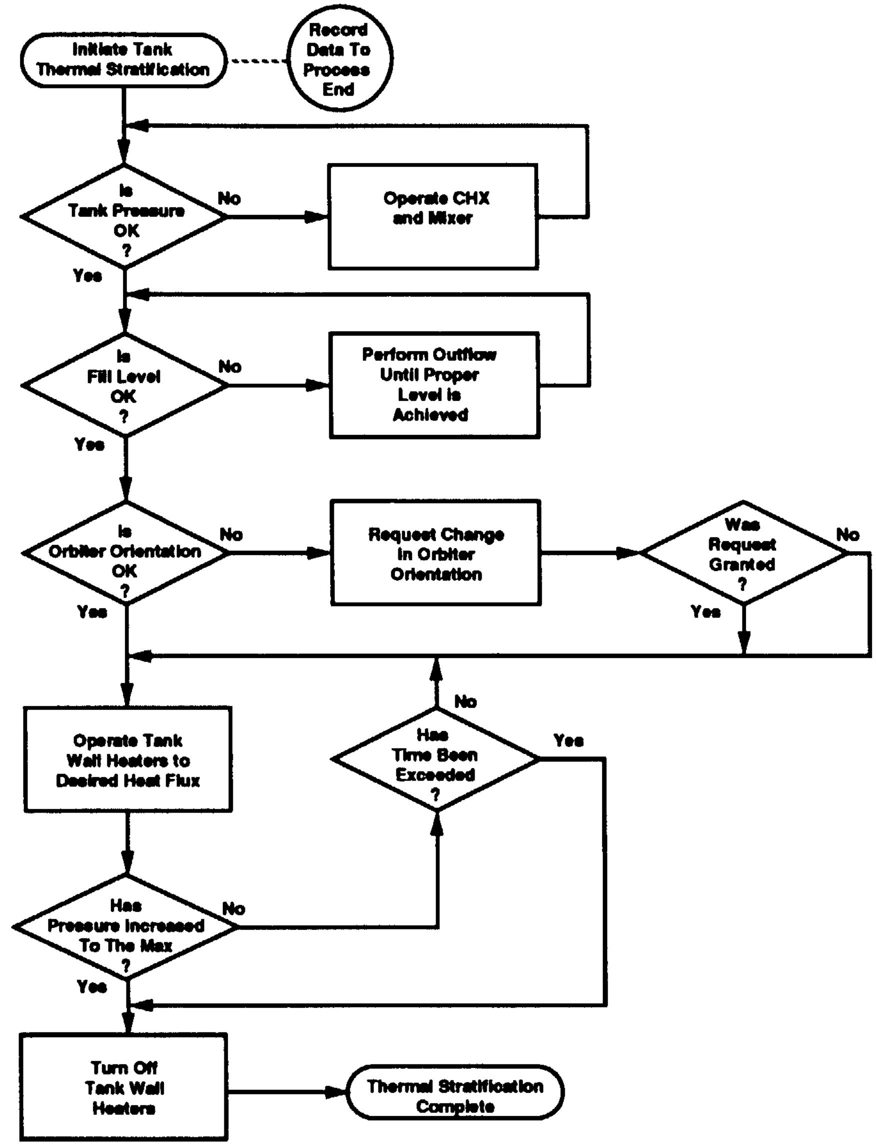


Figure 3.2.2-1 Tank Thermal Stratification Initial Conditions Requirements and Process Flow Chart

steady-state background environment. The approach will be to design the test as if the acceleration level were that due to the drag component only. The deviation in the flow will be considered as noise in the experiment, which can be handled statistically.

A flow chart defining the tank mixing process is provided in Figure 3.2.2-2 along with a summary of the tank active pressure control experiment objectives, principal requirements and derived requirements.

Active pressure control is similar to passive pressure control except that the heat exchanger is not attached to the tank wall or LAD. The heat exchanger is a separate component through which the bulk liquid and two phase fluid flow. There is forced convection heat transfer on both sides of the heat exchanger, and it should be capable of transferring more heat per unit area than the wall mounted heat exchangers. A pump must be included in the bulk liquid flow leg to force the liquid through the CHX. Thermal performance of the CHX is the physical process to be studied in this series of experiments.

Mixing eliminates thermal stratification in the tank. Mixing is accomplished by pumping fluid from the tank and injecting the fluid back into the tank with a jet nozzle. The effect of injecting the fluid into the tank is to impart motion to the bulk liquid which disperses the warm liquid layer. The liquid adjacent to the ullage is cooled as the liquid is mixed, causing condensation on the liquid surface and a decay in tank pressure. The process is complete when the temperature is uniform throughout the gas and liquid, which means the pressure decays until a two-phase state is achieved. Further mixing does not cause any further reduction in pressure and may raise the tank pressure because energy, in the form of work, is added to the tank during mixing. The elimination of thermal stratification is the physical processes to be studied in the tank mixing experiments.

A flow chart defining the tank active pressure control process using the mixer coupled with a compact heat exchanger is provided in Figure 3.2.2-3 along with a summary of the tank active pressure control experiment objectives, principal requirements and derived requirements.

Experiment Set Definition - From the four demonstration and three part active pressure control experiment an integrated experiment set was developed to meet all of the individual requirements. This listing is provided in Table 3.2.2-1 and served as the input for the development of the experiment data base and mission timeline presented in section 9.0.

3.3 CONE Experiment Allocation

3.3.1 CONE Experiment Allocation for the Cryogenic Liquid Storage Demonstration

The principal components used in the cryogenic liquid storage (passive pressure control) demonstrations include the TVS heat exchanger, heaters, flow control valves, the LAD, and instrumentation. The supply tank has an LAD which delivers liquid to the tank outlet. A flow leg withdraws LAD liquid and provides it to the TVS J-T expander. Flow through the J-T expander is routed to the TVS heat exchanger attached to the LAD. The TVS flow passes through the LAD mounted TVS HX and is vented after it exists from the tank. Thermal energy is supplied to the tank with wall mounted heaters so that the heat flux can be controlled for the passive pressure control demonstrations. The sizing of these heaters allows the ambient heat leak to be doubled.

Thermal stratification will not be a initial starting condition for the conduct of passive TVS demonstrations. Control of tank heat flux while the TVS is controlling tank pressure for that condition, as well as controlling the acceleration to some predetermined value and direction will be a part of the test operations. The only components involved in establishing the thermal input to the tank are the tank heaters and normal heat leak. The liquid orientation with background acceleration is arbitrary because the direction of the acceleration will vary and may rotate around the tank several times during a test.

ACTIVE PRESSURE CONTROL EXPERIMENT OBJECTIVE & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - EVALUATE THE ABILITY TO CONTROL CRYOGENIC STORAGE TANK PRESSURE USING A JET-INDUCED MIXER COUPLED WITH A COMPACT HEAT EXCHANGER (CHX)
- FUNCTIONAL REQUIREMENT
  - INVESTIGATE THE EFFECTS OF TANK HEAT FLUX, AXIAL-JET FLOW RATE, CHX FLOW RATE, TANK FILL LEVEL AND ACCELERATION ON:
    1) THERMAL STRATIFICATION OF TEST FLUID
    2) THERMAL DESTRATIFICATION BY AXIAL-JET INDUCED MIXING
    3) PRESSURE DECAY DURING CHX OPERATION
  - COMPARE WITH ANALYTICAL MODEL PREDICTIONS
  - PARTIAL VERIFICATION OF ANALYTICAL MODELS
- PARAMETERS BEING VARIED
  - HEAT FLUX INTO THE TANK
  - ACCELERATION ENVIRONMENT
  - LIQUID FILL LEVEL (MASS GAGE)
  - MIXER FLOW RATE
  - CHX FLOW RATE
- KEY MEASUREMENTS REQUIRED
  - TANK TEMP (BOTH WALL AND FLUID)
  - TANK PRESSURE (INCREASE & DECREASE)
  - ACCELERATION ENVIRONMENT
  - LIQUID/VAPOR INTERFACE POSITION
  - CHX FLOW RATES
  - MIXER PUMP POWER

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
EFFECTS INVESTIGATED FOR MIXING	FILL LEVEL MIXER FLOW RATE	SOFTWARE MIXER PUMP	PARAMETERS WHICH COULD AFFECT MIXING	TD
MIXER TESTS	4	SOFTWARE	ORTHOGONAL MATRIX - 2 FILL LEVELS X 2 MIXER FLOW RATES	EA-CONE-020
JET LOCATION	SETTLED END OF TANK	STORAGE TANK	PERMITS MIXING W/ LIQUID SETTLED OVER PUMP INLET	EA-CONE-013
MIXER FLOW RATES	110 LBM/HR 330 LBM/HR	MIXER PUMP	INHIBIT GEYSERING 40% FULL INDUCE GEYSERING 80% FULL	EA-CONE-027A TD
JET CHARACTERISTICS	TURBULENT	MIXER JET	CONSTANT DIMENSIONLESS MIXING TIME	EA-CONE-027A
MIXING DURATIONS	20 MINUTES MAX.	SOFTWARE	POTH AND VAN HOOK CORRELATION	EA-CONE-027A

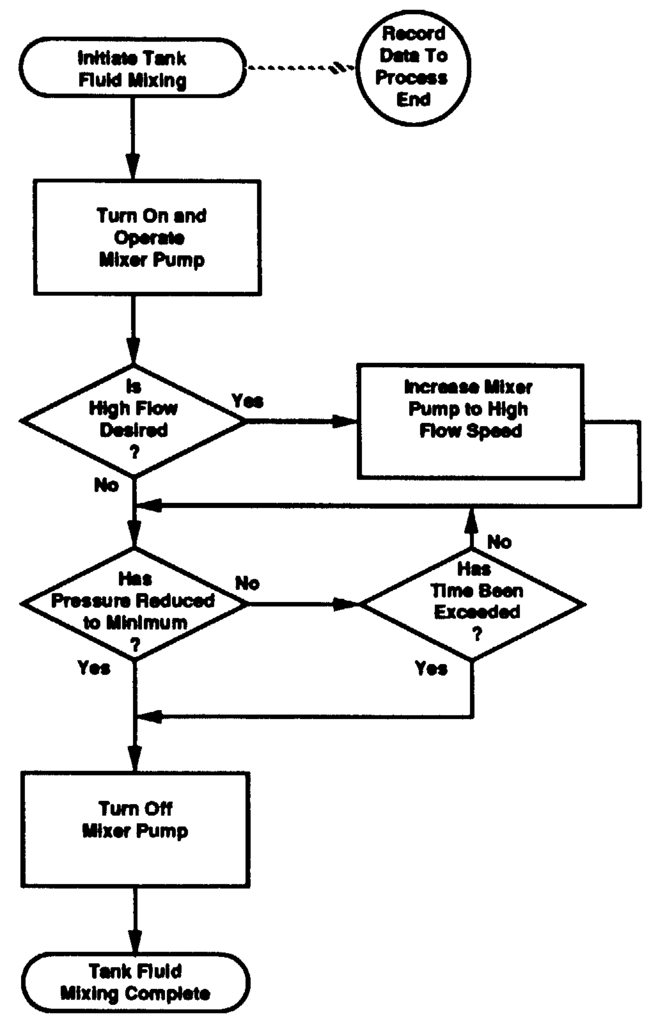
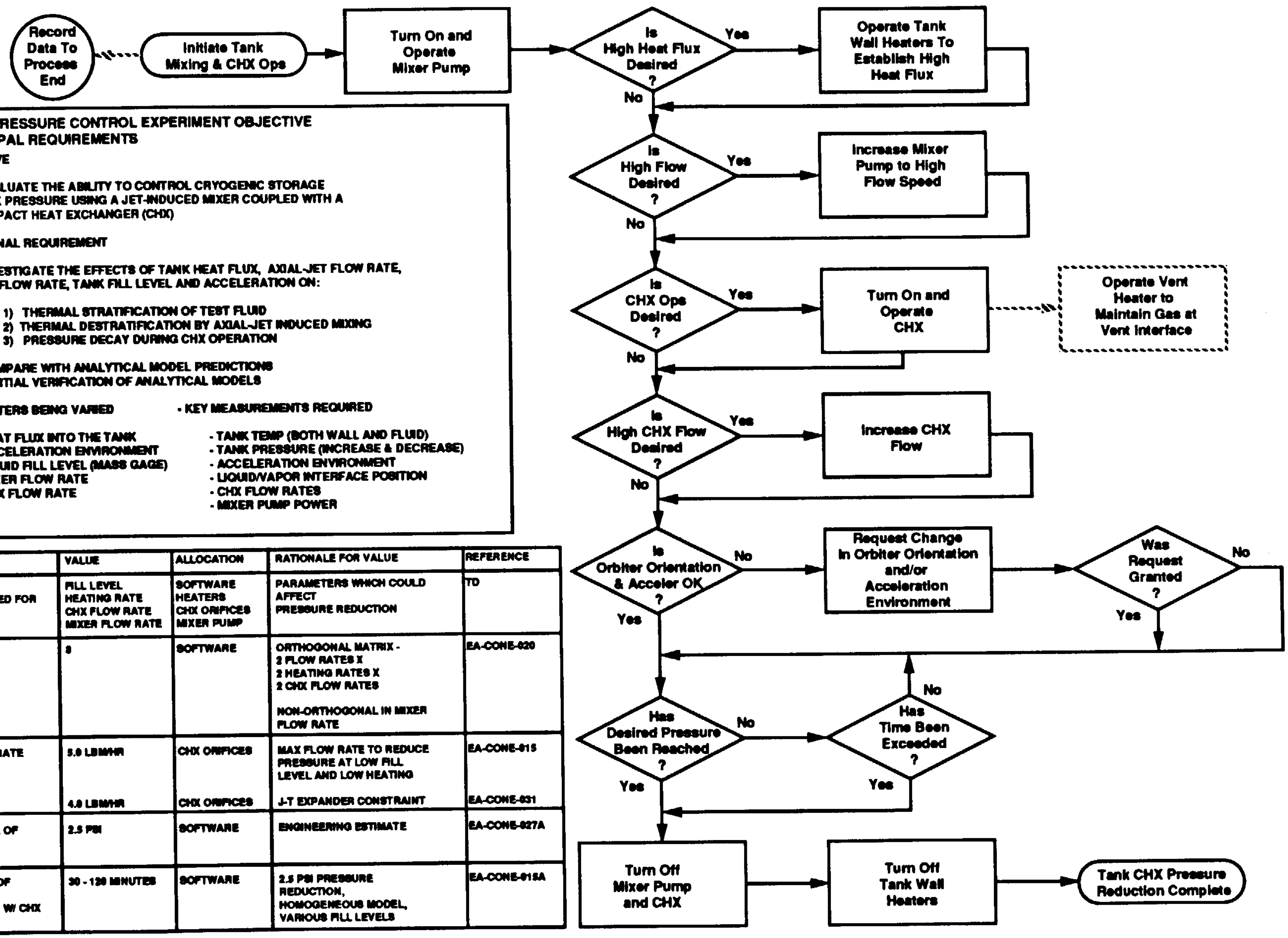


Figure 3.2.2-2 Tank Fluid Mixing Operation Requirements and Process Flow Chart



ACTIVE PRESSURE CONTROL EXPERIMENT OBJECTIVE & PRINCIPAL REQUIREMENTS

- OBJECTIVE
  - EVALUATE THE ABILITY TO CONTROL CRYOGENIC STORAGE TANK PRESSURE USING A JET-INDUCED MIXER COUPLED WITH A COMPACT HEAT EXCHANGER (CHX)
- FUNCTIONAL REQUIREMENT
  - INVESTIGATE THE EFFECTS OF TANK HEAT FLUX, AXIAL-JET FLOW RATE, CHX FLOW RATE, TANK FILL LEVEL AND ACCELERATION ON:
    1) THERMAL STRATIFICATION OF TEST FLUID
    2) THERMAL DESTRATIFICATION BY AXIAL-JET INDUCED MIXING
    3) PRESSURE DECAY DURING CHX OPERATION
  - COMPARE WITH ANALYTICAL MODEL PREDICTIONS
  - PARTIAL VERIFICATION OF ANALYTICAL MODELS
- PARAMETERS BEING VARIED
  - HEAT FLUX INTO THE TANK
  - ACCELERATION ENVIRONMENT
  - LIQUID FILL LEVEL (MASS GAGE)
  - MIXER FLOW RATE
  - CHX FLOW RATE
- KEY MEASUREMENTS REQUIRED
  - TANK TEMP (BOTH WALL AND FLUID)
  - TANK PRESSURE (INCREASE & DECREASE)
  - ACCELERATION ENVIRONMENT
  - LIQUID/VAPOR INTERFACE POSITION
  - CHX FLOW RATES
  - MIXER PUMP POWER

PARAMETER	VALUE	ALLOCATION	RATIONALE FOR VALUE	REFERENCE
EFFECTS INVESTIGATED FOR PRESSURE REDUCTION	FILL LEVEL HEATING RATE CHX FLOW RATE MIXER FLOW RATE	SOFTWARE HEATERS CHX ORIFICES MIXER PUMP	PARAMETERS WHICH COULD AFFECT PRESSURE REDUCTION	TD
PRESSURE REDUCTION	8	SOFTWARE	ORTHOGONAL MATRIX - 2 FLOW RATES X 2 HEATING RATES X 2 CHX FLOW RATES NON-ORTHOGONAL IN MIXER FLOW RATE	EA-CONE-020
CHX FLOW RATE	5.0 LBM/HR	CHX ORIFICES	MAX FLOW RATE TO REDUCE PRESSURE AT LOW FILL LEVEL AND LOW HEATING	EA-CONE-015
	4.0 LBM/HR	CHX ORIFICES	J-T EXPANDER CONSTRAINT	EA-CONE-031
MAGNITUDE OF PRESSURE REDUCTION	2.5 PSI	SOFTWARE	ENGINEERING ESTIMATE	EA-CONE-027A
DURATION OF PRESSURE REDUCTION W/ CHX	30 - 120 MINUTES	SOFTWARE	2.5 PSI PRESSURE REDUCTION, HOMOGENEOUS MODEL, VARIOUS FILL LEVELS	EA-CONE-015A

Figure 3.2.2-3 Tank Fluid Mixing and CHX Operation Requirements and Process Flow Chart

Table 3.2.2-1 Integrated Experiment Set

Cryogenic Liquid Storage (performed at background acceleration level)
- Test 1 Control Pressure with TVS at Low Heat Flux - High Fill Level
- Test 2 Control Pressure with TVS at Nominal Heat Flux - High Fill Level
- Test 3 Control Pressure with TVS at Low Heat Flux - Low Fill Level
- Test 4 Control Pressure with TVS at Nominal Heat Flux - Low Fill Level

Liquid Nitrogen Supply (performed at TBD Orbiter attitude to expel LN2)
- Test 1 Outflow LN2 to Low Fill Level and Chilldown Pressurant Bottle - OHX On
- Test 2 Outflow LN2 to Near Depletion with OHX Off

Pressurant Bottle Recharging (performed at background acceleration level)
- Test 1 Charge Pressurant Bottle and Allow to Warm-up (Without Chilldown)
- Test 2 Charge Pressurant Bottle and Allow to Warm-up (With Chilldown)

LAD Performance (Performed with Orbiter in high drag attitude with RCS used for settling)
- Test 1: Outflow LN2 to LAD Depletion & Determine Residuals

Active Pressure Control

Stratification
- Test 1: Stratify at High Heat Flux With Unsettled Fluid - High Fill Level
- Test 2: Stratify at High Heat Flux With Settled Fluid - High Fill Level
- Test 3: Stratify at High Heat Flux With Unsettled Fluid - Low Fill Level
- Test 4: Stratify at High Heat Flux With Settled Fluid - Low Fill Level

Mixing
- Test 5: Destratify with Mixer at Low Flow Rate With Unsettled Fluid at Nominal Heat Flux - High Fill Level
- Test 6: Destratify with Mixer at High Flow Rate With Settled Fluid at Nominal Heat Flux - High Fill Level
- Test 7: Destratify with Mixer at High Flow Rate With Unsettled Fluid at Nominal Heat Flux - Low Fill Level
- Test 8: Destratify with Mixer at Low Flow Rate With Settled Fluid at Nominal Heat Flux - Low Fill Level

Mixing and CHX Ops
- Test 9: At Nominal Heat Flux Reduce Pressure with Mixer at Low Flow Rate & Low CHX Flow - High Fill Level
- Test 10: At High Heat Flux Reduce Pressure with Mixer at High Flow Rate & Low CHX Flow - High Fill Level
- Test 11: At Nominal Heat Flux Reduce Pressure with Mixer at High Flow Rate & High CHX Flow - High Fill Level
- Test 12: At High Heat Flux Reduce Pressure with Mixer at Low Flow Rate & High CHX Flow - High Fill Level
- Test 13: At Nominal Heat Flux Reduce Pressure with Mixer at High Flow Rate & Low CHX Flow - Low Fill Level
- Test 14: At High Heat Flux Reduce Pressure with Mixer at Low Flow Rate & Low CHX Flow - Low Fill Level
- Test 15: At Nominal Heat Flux Reduce Pressure with Mixer at Low Flow Rate & High CHX Flow - Low Fill Level
- Test 16: At High Heat Flux Reduce Pressure with Mixer at High Flow Rate & High CHX Flow - Low Fill Level

The passive pressure control experiments use the LAD mounted heat exchanger to remove heat from the tank. Liquid is withdrawn form the tank, throttled through the J-T expander, routed through the heat exchanger and vented overboard. TVS flow is controlled by a single flow control orifice which is operated by latching valves. Valve operation is controlled by tank pressure and results in the TVS flow either being on or off. These tests are performed without the mixer.

3.3.2 CONE Experiment Allocation for the Liquid Nitrogen Supply Demonstration

The components needed to accomplish tank outflow consist of the storage tank with liquid acquisition device, gaseous nitrogen pressurization system, transfer line to high flow vent, pressure and temperature instrumentation, and a transfer line flow meter. The transfer line has dual orifice flow rate capability for each of the two flow rates proposed for this demonstration. Outflow will be accomplished by expelling liquid from the top of the tank where the outflow line is placed, then routing it through or bypassing the the OHX , and consequently discharging liquid through the high flow vent.

The liquid acquisition device consists of a three-channel design to allow for a maximum ullage space without exposing any of the channels during launch. Each channel is designed such that the screen width and channel depth provides adequate surface and cross sectional area. The channels are positioned circumferentially along the tank axis next to the wall. Main engine firing acceleration levels during ascent can become high enough to effectively break down any portions of the screen that are exposed to ullage. If a breakdown condition would result, it could be difficult to re-establish a completely filled LAD prior to conducting the expulsion tests.

The pressurization system will provide the subcooling necessary to establish desirable thermodynamic conditions of the fluid prior to acquisition and transfer. The compact heat exchanger (CHX) will not be used for subcooling the outflow, but instead, the outflow heat exchanger will be used to subcool the fluid in the transfer line for one of the tests. The subcooling level and outflow rate will be established by the pressure level imposed in the tank. Tank pressurization provides a uniform subcooled fluid thermodynamic state which is desirable for maintaining control of uniform thermal properties of the expelled liquid. When the tank fluid is exposed to the warm ullage during the low flow rate outflow the quality of fluid in the tank will degrade to the point of requiring CHX conditioning before bottle recharge, which is the next sequential operation.

A flow meter is used in the transfer line to measure the outflow rate and to measure the fluid quality of expelled fluid. In-tank temperature and level sensors will also be used to determine liquid levels and fluid orientations during these tests.

3.3.3 CONE Experiment Allocation for the LN2 Recharge Bottle Demonstration

The principal components used in the pressurant bottle recharge experiment include the tank, flow line connecting to the LN2 storage tank outflow line, an overboard vent line, associated valving and instrumentation. The pressurant bottle outer surface coating is white paint to aid in the desired tank warm-up time.

Storage tank outflow line fluid is introduced into the recharge bottle via an isolation valve and a check valve to provide a two inhibit isolation of the high pressure bottle from the low pressure outflow line. Both chilldown and recharge fluid are introduced into the bottle in this manner. The bottle contains a single penetration that must accommodate inflow and outflow operations. A vent interface allows venting of the bottle contents overboard out of the high flow space vent. This line contains two valves to isolate bottle pressure from the vent Pressure relief protection during bottle warm-up is provided in the form of an automatic control network and a back-up parallel burst disk and relief valve. Instrumentation includes two bottle and one internal probe mounted temperature sensors and redundant pressure transducers.

The recharge bottle is launched serviced with GN2. This GN2 is used for the first tank outflow before the remaining bottle contents are dumped overboard in preparation for the first recharge.

3.3.4 CONE Experiment Allocation for the Active Pressure Control Experiment

The principal components used in the active pressure control experiments are tank wall heaters to induce stratification, a LN2 mixer pump and axial jet to perform fluid mixing coupled with a CHX/flow control for energy removal from the tank fluid and instrumentation.

The active pressure control testing consists of three separate operations. The three are tank stratification, tank contents mixing, and pressure reduction via an active pressure control system. The first operation, Thermal stratification, will be induced by turning off the TVS and CHX, controlling the acceleration to some predetermined value and direction (which for some tests may be uncontrolled background), and activating the tank wall mounted heaters to the high value. The only components involved in establishing the thermal stratification are the wall mounted heaters. The liquid orientation with background Orbiter acceleration will be arbitrary since the direction of the acceleration will vary and may rotate around the tank several times during a test. Orbiter high drag modes requested during normal crew sleep periods many not be of sufficient magnitude to establish a settled stable interface, but is the most quiescent Orbiter acceleration regime possible. Settling accelerations using the PRCS in a pulsed mode will provide a stable interface when desired, depending on availability of such thrustings from the Orbiter.

The mixing tests are to be performed after the liquid in the tank has been thermally stratified. The liquid in the tank is mixed by pumping it through the inactive CHX, and injecting the liquid into the tank with the axial jet. During the mixing tests there will be no flow through the cold side of the CHX. Flow rate through the system will be controlled by the variable speed pump. Heat flux during mixing will be at ambient levels only. The tank heaters will be off.

The active pressure control experiments will use the CHX and the pump to condition liquid in the tank, cool the liquid in the CHX, and inject the liquid into the tank with the axial jet. The two-phase flow is controlled by a JT expander and fixed orifices and latching valves in the warm part of the system that is then vented directly overboard. Flow control for the two phase side flow will be provided by fixed orifices that are downstream of the CHX. The mixer side flow control is to be accomplished by varying the pump speed.

3.3.5 CONE Experiment Allocation for LAD Performance (Expulsion Efficiency) Demonstration

The components and systems for the nitrogen LAD expulsion efficiency test required to conduct this experiment are the storage tank with LAD, the transfer line, the pressurization subsystem, the high flow/backpressure vent systems and instrumentation.

The liquid acquisition device is the same three-channel device that is used for other tank outflows. The outflow heat exchanger (OHX) will be bypassed and turned off during the expulsion test. The transfer line flow meter will be used to integrate the outflowing LN2 to depletion and provide a measure of when the LAD breaks down as indicated by two phase flow. The CHX vent system with CHX flow meter will be used to measure the residuals in the LAD and tank following the liquid expulsion for determination of the LAD expulsion efficiency.

3.4 Support Subsystem Requirements

The support subsystems provide the supporting structure to attach the payload, the external thermal control of the payload, the input power for the payload, the command and data handling for the payload, and the computer processing for control of the payload.

The driving requirements on the design of the CONE payload are:

- The MPESS structure used to support CONE
- The available power from the Hitchhiker Avionics Unit
- The data rate available to fit in the realtime downlink over the Shuttle S-band link
- The astronaut availability to control CONE operations
- The length of a typical Shuttle mission

4.0 EXPERIMENT SUBSYSTEM DEFINITION

The CONE Experiment Subsystem is composed of the following major elements:

- LN2 storage tank
- LN2 storage tank valve module
- GN2 pressurization & LN2 bottle recharge module

The functional requirement of the experiment subsystem is to provide the capability to perform the required demonstrations, experiments, and tests of the experiment set which was defined in section 3.0. This will be accomplished with the configuration defined in this section.

4.1 Experiment Subsystem Evolution Overview

An integrated experiment subsystem schematic has been baselined and is included in Figure 4.1-1. Included are design details, instrumentation locations and/or groupings, and plumbing/flow routings and component relationships. Control network functions are also shown. The experiment subsystem includes the following major functional elements:

- Storage tank pressure vessel
- Storage tank vacuum jacket
- Pressurization system
- Fluid distribution and control plumbing and components
- Pressurant recharge bottle
- Instrumentation for all elements

Since the Concept Review (CR) the experiment subsystem has not been substantially modified. The following changes have been made to the finalized baseline schematic since the CR:

- LN2 storage tank
  - Delete instrumentation rake, sensors will be mounted to the lad support structure
  - Change support straps from 8 to 6
  - Add control network C11 for wall heater power removal

- LN2 storage tank valve module (panel A)
  - Add control networks C9 & C10 for line heater control
  - Add test ports to tank burst disks (BD2A & BD3A)

- GN2 pressurization and LN2 bottle recharge module (panel B)
  - Replumb final outflow line isolation valve (V6B)
  - Add provisions (MV4B) for GN2 ground loading of the recharge bottle
  - Add valving (V9B & V10B) for venting the recharge bottle
  - Add separate vent for the recharge bottle
  - Add a pressurant crossover between the recharge bottle GN2 storage

- General
  - Add identification to all components
  - Add provisions for future fluid transfer (receiver tank)

The experiment subsystem concept definition and mainly the LN2 storage tank size, shape and orientation with respect to the HH-M carrier and the Orbiter for acceleration and attitude considerations became the design driver for the experiment subsystem. After the LN2 storage tank was sufficiently defined the remaining components of the subsystem evolved into two modules that conformed to

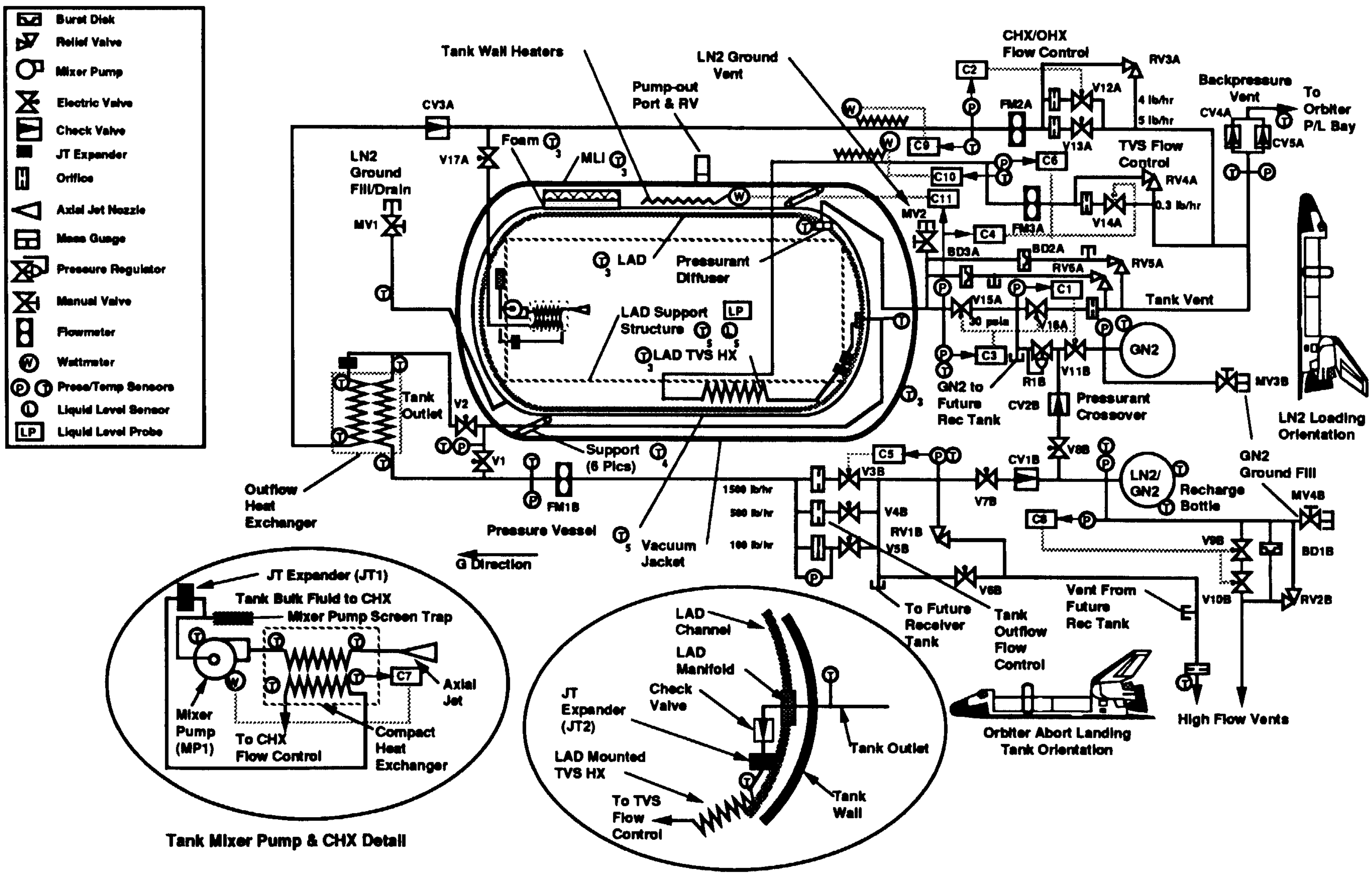


Figure 4.1-1 Integrated Experiment Schematic

standard mountir plates that are HH-M provided. In evolving the experiment concept, an experiment set defining the experiment requirements was assembled as previously defined in section 3.0 which also included an allocation of these requirements, along with operational and mission requirements to various elements of the experiment subsystem. When the LN2 storage tank design was integrated with GN2 pressurization, plumbing, valving, recharge bottle, and instrumentation, an initial experiment concept was developed to meet these needs and a point of departure was thus created to satisfy the requirements. This concept was iterated and refined over the duration of the program to meet changing experiment set needs and to respond to more sophisticated analyses that better characterized experiment processes.

4.2 LN2 Storage Tank

This tank has a pressure vessel of 0.226 m^3 (8 ft^3) capable of holding 171 kg (375 lbs) of LN2 at 95% full and is completely contained by a vacuum jacket (VJ). To maintain a shape relationship to typical space based transfer vehicle tankage and in order to provide for a stable fluid interface, a cylindrical tank shape was selected. The overall tank VJ has a diameter of 68.6 cm (27 in) and a length of 121.9 cm (48 in) to provide the largest size tank that could be mounted to the front face of the Hitchhiker-M carrier. The pressure vessel (PV) has a diameter of 58.4 cm (23 in) and contains a total communication LAD with an outlet at the top of the tank. A vent/pressurization penetration which feeds directly into the tank via a diffuser is located at the top end so that contact with ullage is maintained for both horizontal and vertical positions of the tank. Pressurant is introduced into the tank by this line. An axial jet spray system is provided through which liquid can be introduced from a mixer pump to provide mixing of the bulk fluid. Mixer pump fluid is passed through a compact heat exchanger (CHX) where energy can be removed from the tank to actively control or reduce tank pressure. An internal thermodynamic vent system (TVS) heat exchanger (HX) routed on the LAD is provided to cool the bulk fluid and passively control tank pressure. Thermal control heaters uniformly cover the pressure vessel and are used to vary the heat flux for pressure control and stratification experiments. A layer of foam insulation covers the heater blanket to provide protection against a loss of annular vacuum and limit the venting potential for this off-nominal case. Multi-layer insulation (MLI) is located over the foam insulation for nominal on-orbit control of tank heat leak. All plumbing penetrations from the PV are routed internal to the VJ and exit at the girth ring area. An outlet heat exchanger (OHX) mounted to the VJ girth allows for subcooling of the tank outflow. The PV connects to the VJ with a strap suspension system. Figure 4.2-1 shows the layout drawing for the tank.

4.2.1 Pressure Vessel (PV)

This tank is an integrated cylindrical assembly consisting of a 0.226 m^3 (8 ft^3) 2219-T62 aluminum PV holding a quantity of 216 liters (57 gals) of LN2 at a maximum operating pressure of 311 kN/m^2 (45 psia) when loaded to 95% full. The assembly consists of two hemispherical shaped domes welded to an equatorial barrel section 43 cm (17 in) long by 58.4 cm (23 in) diameter. The dome wall thicknesses are a minimum of 0.019 mm (0.075 in) with increasing thickness at the poles and at the attachment girth ring interface of 0.48 cm (0.19 in). An increased thickness of 0.48 cm (0.19 in) is also provided at the 3 strap attachment locations on each dome. The barrel section also has a tapered wall thickness of 0.48 cm (0.19 in) at the weld interface and a minimum membrane thickness of 0.28 cm (0.11 in). These wall thicknesses resulted from a 4.0 safety factor (derived requirement) imposed on the design yield point using a maximum analyzed pressure of 1497 kN/m^2 (217 psia). This configuration results in a leak before burst design and a design that will not yield at the 200 psia "burst pressure". A requirement for design collapse pressure has also been incorporated into the design. The PV contains the following internal parts:

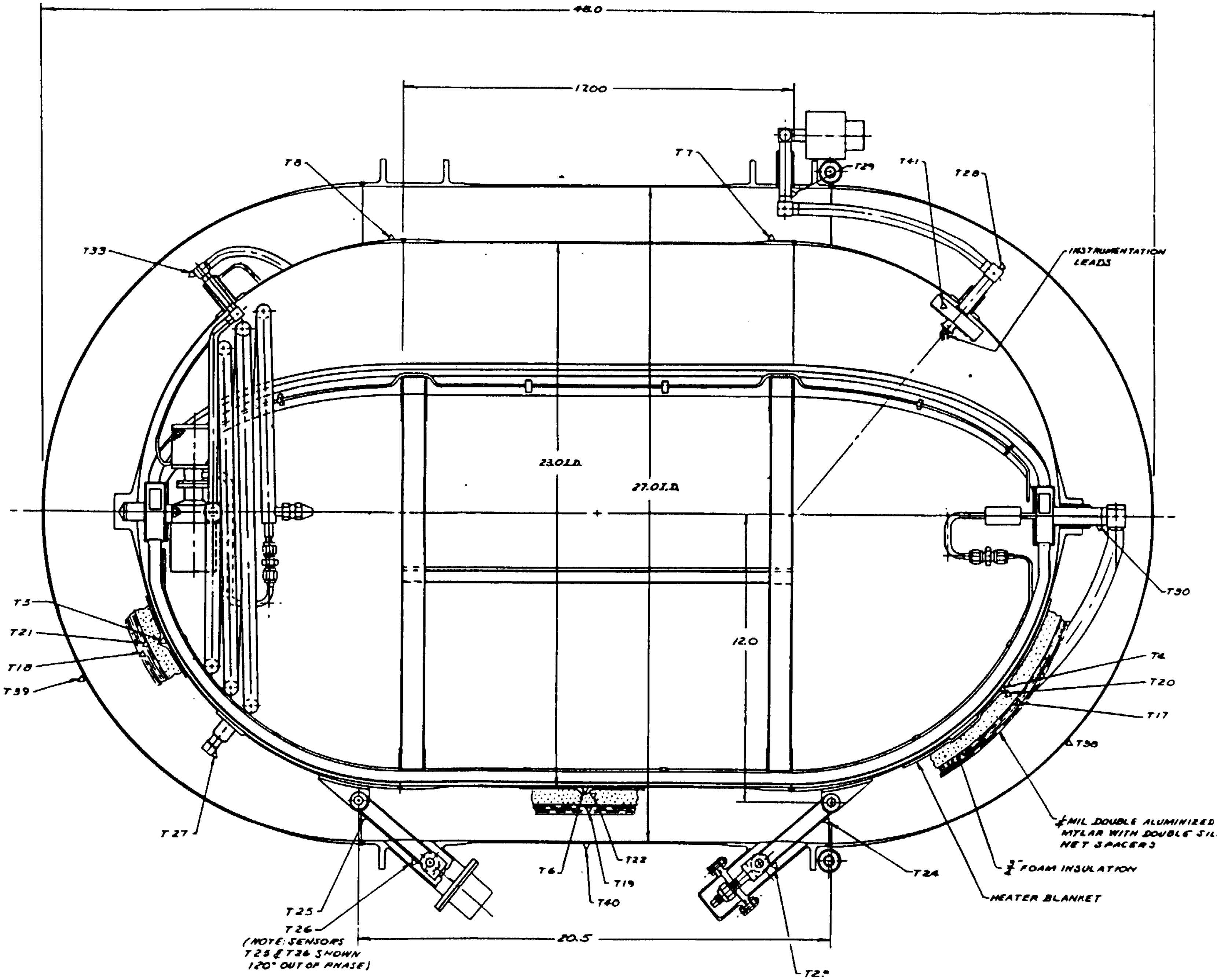


Figure 4.2-1 LN2 Storage Tank Layout Drawing

Liquid Acquisition Device (LAD) - The PV contains a total communication LAD that interfaces at the poles of the tank (± Y axis). It makes use of the surface tension forces produced at the interface between the gas and liquid within the pores of a fine-mesh screen and is the key element for subcritical gas-free expulsion of LN2 in the low-g space environment. The outlet end is fixed by a welded stainless steel to aluminum bi-metallic transition tube between the acquisition device and the PV. Three 2.54 cm x 1.27 cm (1 in x 0.5 in) continuous stainless steel channels manifolded at the outlet make up the configuration which is shown in Figure 4.2-2. The channels are continuous, terminating the flow passage such that the three channels join at the top of the tank to provide rigidity and support. The channels are oriented to prevent exposure of the screen to the tank ullage during the ground loading and launch phase of the mission. The 325 x 2300 stainless steel double Dutch twill screen is welded to the channel side facing the tank wall and is backed up by perforated plate for structural support. This configuration provides for continuous screen continuity within each channel to maintain the necessary wetting and wicking characteristics near the PV wall that result in high expulsion efficiencies estimated to be greater than 99.5% for the storage tank and high resistance to breakdown. Channel support structure provides mounting for tank fluid temperature and level sensors at various locations with respect to both fill level and position within the fluid.

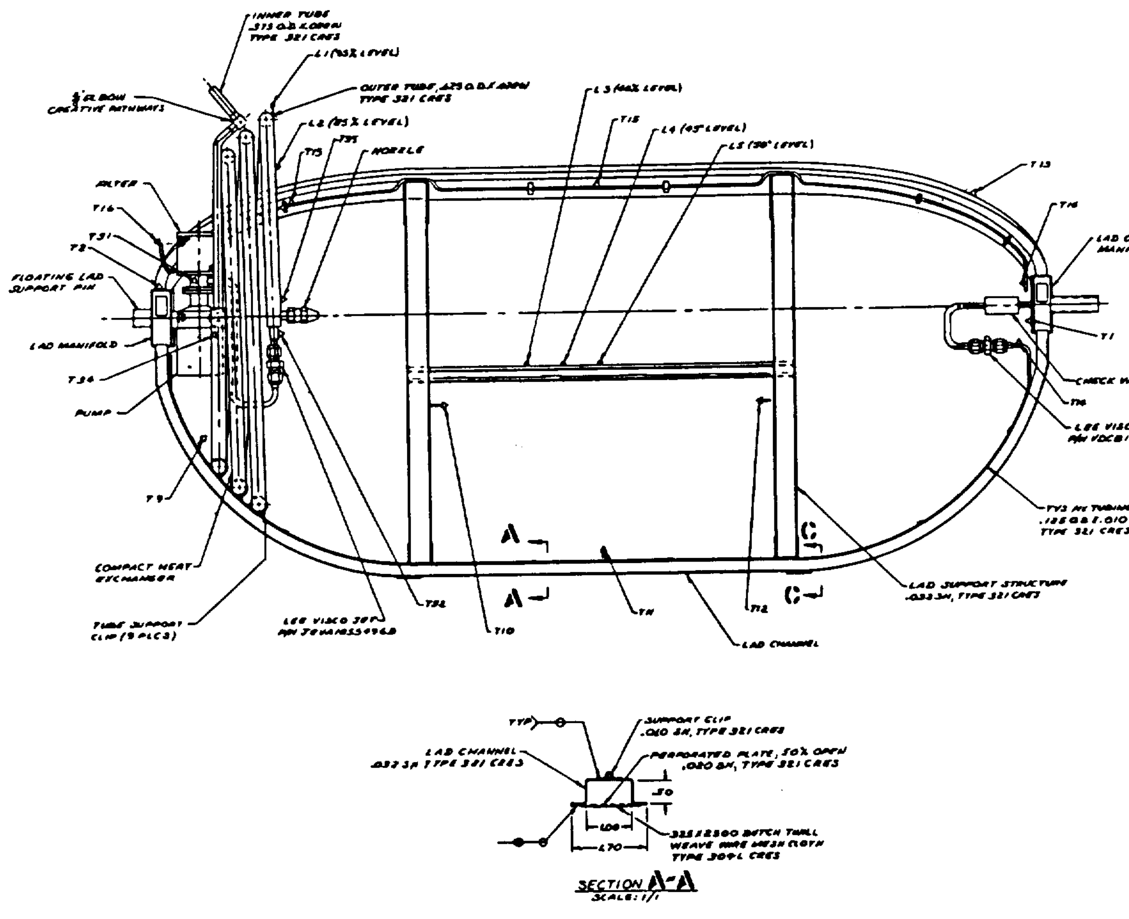


Figure 4.2-2 Storage Tank LAD Configuration

Axial Jet Spray - The prime mixing mode for the storage tank for purposes of reducing thermal stratification will utilize a single 1.27 cm (0.5 in) diameter jet which is located at the outlet end of the tank along the tank centerline with the spray directed towards the vent end. Mixer pump flow between 50 to 150 kg/hr (110 to 330 lb/hr) can be routed to the jet so that mixing can be evaluated for both geysering and non-geysering conditions. Flow rate is controlled by varying the speed of the pump.

LAD Mounted TVS HX - The LAD does not control the location of the ullage within the tank in a low-g environment, so venting of the tank (controlling tank pressure) in the conventional manner of opening the tank vent is not possible. The TVS HX internal to the tank mounted on the three LAD channels provides a means for relieving the tank pressure increase due to heat input. The TVS HX will be utilized to remove heat from the cryogen in the CONE storage tank. This HX can only be used in one operating mode. This operational mode will have a flow rate that exceeds the nominal heat leak case to reduce tank pressure and operates within a .69 kN/m^2 (0.1 psia) setpoint where the TVS is operated when the top of the set point is reached and turned off at the low end of the span.

In the TVS, LN2 is withdrawn from the LAD and passed through Joule-Thomson expanders. This chilled fluid at a reduced pressure is then routed into a manifold that diverts the flow into a 0.48 cm (0.1875 in) diameter heat exchanger tube mounted to the back side of each of the three LAD channels. The vented fluid is used as a refrigerant to reduce or maintain the net heat input to the tank based on TVS flow rate.

The other function for the HX will be to ensure vapor free operation of the tank Liquid Acquisition Device (LAD). By routing the HX tubing properly over the surface of the LAD, the cooling capability of the fluid can be used to condense any vapor bubbles that might form in the LAD.

Vent Line Pressurant Diffuser - The pressurant diffuser at the end of the vent/pressurization line is designed to disperse incoming GN2 pressurant and to prevent direct pressurant impingement on the liquid. It is important, for optimized use of the fixed quantity of stored GN2 pressurant, not only to introduce pressurant at a warm condition, but also to prevent pressurant mixing into the liquid.

External Wall Mounted Heaters - Tank stratification is induced by external wall mounted surface heaters that provide both uniform and very low heating to establish heat fluxes of 2.8 and 22.7 w/m^2 (0.9 and 7.2 Btu/hr-ft^2). Heater blankets that provide heat fluxes of 1.4 and 21.3 w/m^2 (0.45 to 6.8 Btu/hr-ft^2) are required, assuming the parasitic heat flux of 1.4 w/m^2 (0.45 Btu/hr-ft^2) persists regardless of heater operation. Total heater power for these cases varies from 3.0 to 40 watts.

4.2.2 Vacuum Jacket (VJ)

An annular vacuum region of 5 - 10 cm (2 - 4 in) surrounds the pressure vessel and is provided by a cylindrical vacuum jacket made of 2219-T852 aluminum. The assembly, illustrated in Figure 4.2-3, consists of spherical shaped domes welded to an equatorial barrel section 52.1 cm (20.5 in) long by 68.6 cm (27 in) in diameter. The dome wall thicknesses are 0.25 cm (0.10 in) tapering to 0.51 cm (0.20 in) at the weld area. The barrel section has a membrane wall thickness of 0.19 cm (0.075 in) and has added strength provided by girth ring supports. Wall thickness at the weld interface is 0.51 cm (0.20 in). These wall thicknesses resulted from a 1.61 safety factor (derived requirement) imposed on the design yield point using a maximum analyzed collapse pressure of 137.9 kN/m^2 (20 psia). The VJ contains the following internal/external parts:

Multi Layer Insulation (MLI) - The thermal design of the CONE supply tank MLI system was based on achieving a nominal heat leak into the tank. Via the use of a Thermodynamic Vent System (TVS) and Multi-Layer Insulation (MLI) the heat flux into the tank can be controlled to whatever is required. The heat flux value for the CONE supply tank was set at of 1.42 w/m^2 (0.45 $Btu/hr\text{-}ft^2$) per direction from NASA LeRC. This value resulted in a required tank heat leak of 2.6 w (9.0 Btu/hr).

The above were used to determine the derived design requirements of the tank insulation system. Analysis of the tank lockup case showed that the desired heat flux can be obtained with 1.2 cm (0.46 in) of MLI on the pressure vessel. The MLI configuration consists of 0.0127 mm (0.5 mil) double aluminized Mylar radiation shields separated by two Dacron B4A net spacers, assembled to a layer density of 20 reflectors/ cm (50/in).

Foam Insulation - It was desirable to limit the heat leak to the pressure vessel and, consequently, the storage tank outflow rate in case of a loss of vacuum integrity. This was accomplished by including in the design 1.27 cm (0.5 in) of sprayable polyurethane foam on the exterior surface of the pressure vessel, which also prevented condensation of LO2 on the pressure vessel surface. The MLI is applied over the foam surface.

Expose VJ Annulus to Space Environment - A relief valve is mounted on the VJ to relieve annulus pressure to space in case of a leak inside vacuum jacket. Pressure could increase inside the VJ if one of the lines or fittings inside the VJ leaked.

Outflow Heat Exchanger (OHX) - The functional requirement of the outflow heat exchanger (OHX) system is to provide thermal subcooling of the outflowing liquid during one of the two liquid supply demonstrations. The OHX provides 8.3 K (15 R) of subcooling at the 45 kg/hr (100 lbm/hr) outflow rate. The OHX can also be bypassed for the 681 kg/hr (1500 lbm/hr) pressurant bottle recharge liquid transfer. The OHX is mounted to the girth area of the VJ as shown in Figure 4.2-3.

Support Straps - The PV is supported to the VJ by 6 composite tension support straps. The straps are mounted to thickened areas on the PV domes and to the VJ barrel section. This allows for the installation of the completed PV and MLI including all plumbing penetrations that interface with the VJ barrel to be assembled and installed prior to the closure of VJ dome to barrel section welds.

4.3 LN2 Storage Tank Valve Module (A)

All components that interface with the back pressure vent and provide LN2 storage tank pressure relief or isolation for TVS, CHX, OHX flow rate control and tank venting/pressure introduction, as well as instrumentation for flow monitoring are accommodated by this module as shown in Figure 4.3-1. Redundant mechanical burst disk/relief assemblies provide overpressure protection for the tank at 345 kN/m^2 (50 psia). All components (exclusive of instrumentation) that are located on this panel are identified by an "A" ID number.

The entire module is unitized by a 1.6 cm (5/8 in) thick fiberglass mounting plate that is sized 63.5 cm (25 in) wide by 99 cm high (39 in) to mount to a standard HH-M side mounting plate. Components and plumbing mount to the module plate which in turn is attached to the HH-M plate structure. This module contains the following functions:

- A 6 mm (1/4 in) 207 kN/m^2 (30 psia) regulated GN2 pressurant line from the GN2 pressurization & LN2 bottle recharge module interfaces with the LN2 storage tank vent line to provide pressurant for tank outflow.

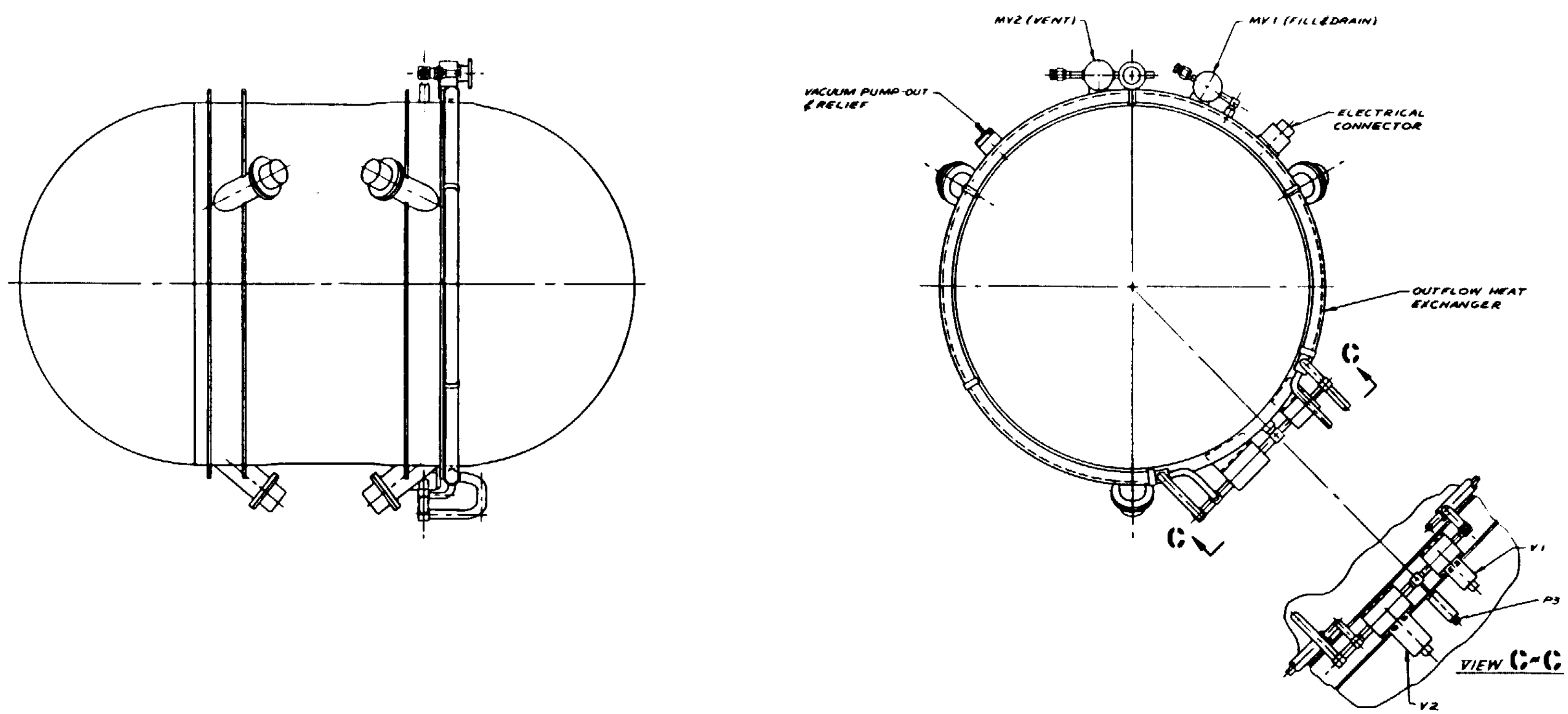


Figure 4.2-3 Storage Tank Vacuum Jacket External Design Details

• The LN2 storage tank vent line and series redundant motor driven electrically operated isolation valves interface to the backpressure vent.
• Off the LN2 storage tank vent line parallel burst disk/relief combinations provide overpressure protection for the tank at 345 kN/m^2 (50 psia).
• Heat exchanger flow control torque motor valves and associated flow control orifices and flow metering provide for the following:

1. TVS - 0.14 kg/hr (0.3 lb/hr)
2. CHX - 1.8 or 2.3 kg/hr (4 or 5 lb/hr)
3. OHX - 4.1 kg/hr (9 lb/hr)

• Selection capability for operating either the TVS, CHX or OHX is provided.
• Five pressure transducers provide pressure data for the:

1. LN2 storage tank
2. Regulated GN2 pressurant
3. CHX/OHX flow
4. TVS flow
5. Backpressure vent

• Trapped volume relief protection is provided in two locations.
• The backpressure check valves are also contained on the module.

4.4 GN2 Pressurization and LN2 Bottle Recharge Module (B)

Components associated with pressurant storage, ground servicing, regulation and distribution, as well as the LN2 storage tank outflow line and the LN2 recharge bottle are assembled into a self contained module as shown in Figure 4.4-1. Pressurant storage is provided by two spherical 35.6 cm (14 in) diameter 0.023 m^3 (0.83 ft ^{3}) tanks pressurized to 20670 kN/m^2 (3000 psia) on the ground prior to flight. Each tank stores 5 kg (11 lbs) of GN2. Ground GN2 servicing interfaces and manual valving for loading GN2 into the pressurant bottles are incorporated. The outflow line from the LN2 storage tank with flow control for 45, 227 and 682 kg/hr (100, 500 and 1500 lb/hr), respectively is provided, as is the supply line to the LN2 recharge bottle. Interfaces to the high flow in-space vents are accommodated by this module. A fixed regulator controls delivered pressurant to 207 kN/m^2 (30 psia) for introduction into the LN2 storage tank. All components (exclusive of instrumentation) that are located on this panel are identified by a "B" ID number.

The entire module is unitized by a 1.6 cm (5/8 in) thick fiberglass mounting plate that is sized 63.5 cm (25 in) wide by 99 cm high (39 in) to mount to a standard HH-M side mounting plate. Components and plumbing mount to the module plate which in turn is attached to the HH-M plate structure. This module contains the following functions:

• Primary GN2 pressurant storage is provided at 20700 kN/m^2 (3000 psia) with a manual 6 mm (1/4 in) AN ground servicing port and isolation valve. Stored pressurant is delivered to a manual fixed set point 207 kN/m^2 (30 psia) regulator by a solenoid isolation valve. Secondary GN2 pressurant storage is provided by the LN2 recharge bottle at similar pressure, line size and with independent ground loading isolation. This secondary pressurant is delivered by a crossover line containing a solenoid isolation valve.
• Pressurant for the first LN2 storage tank outflow is provided by the recharge bottle. At the end of the outflow the remaining pressurant is vented overboard and the bottle is exclusively used for recharge demonstrations for the remainder of the mission. The recharge bottle connects to the high flow GN2 vent by two in series solenoid isolation valves that connect to the crossover line.
• The LN2 storage tank outflow line (transfer line) interfaces with the module. On the module outflow flow control motorized ball valves and associated flow control orifices and flow metering provide for 45, 227 and 682 kg/hr (100 lb/hr, 500 lb/hr and 1500 lb/hr).

• A connection to the outflow line, check valve and pilot operated isolation valve provides liquid to the recharge bottle. A parallel burst disk/relief valve combination provides overpressure protection for the bottle during recharge warm-up.
• Six pressure transducers provide pressure data for the:

1. Outflow line before flow control
2. Outflow line after flow control
3. GN2 bottle
4. LN2 recharge bottle (2 places)
5. 45 kg/hr (100 lb/hr) flow control orifice

• Trapped volume relief protection is provided for the outflow line

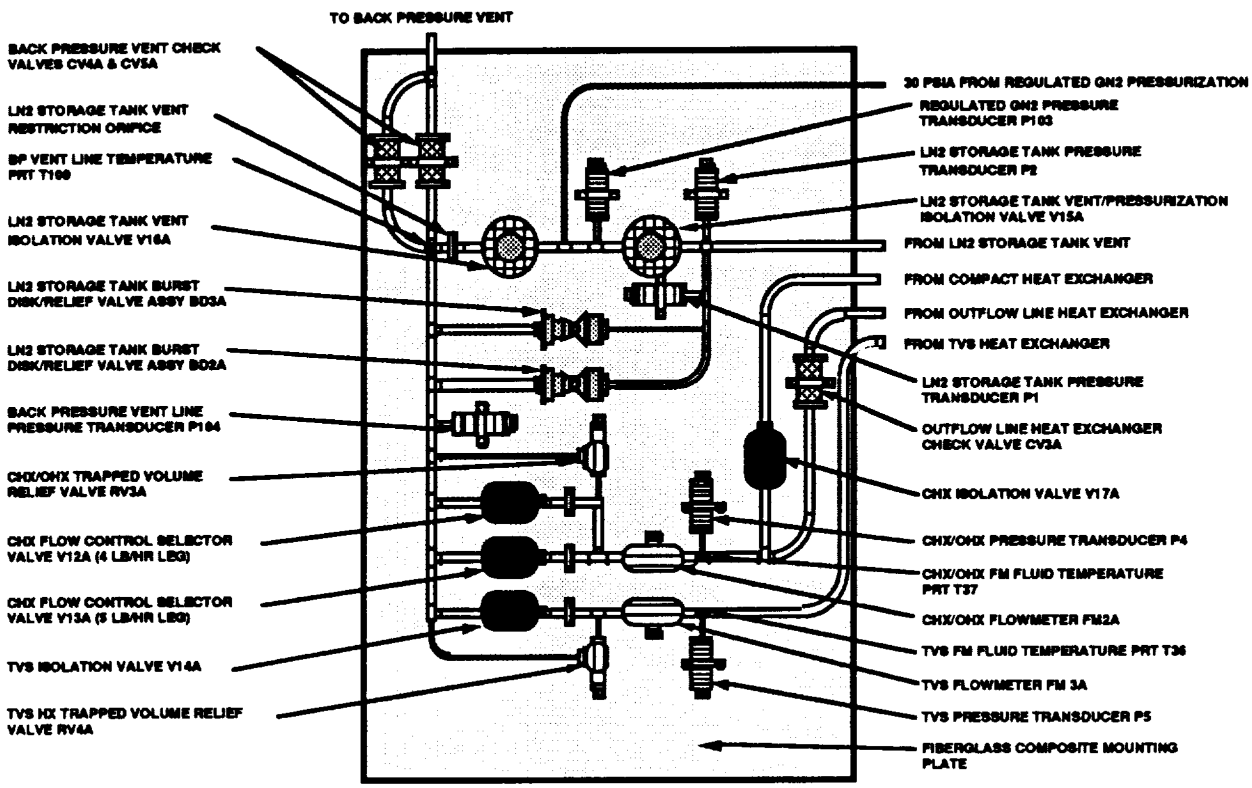


Figure 4.3-1 LN2 Storage Tank Valve Module

4.5 Instrumentation

This section discusses those measurements required to successfully conduct the CONE demonstrations and experiment categories of investigations which were defined in Section 3.0 and instrumentation necessary to obtain the required data for an understanding of the associated processes, as well as for the verification and correlation of analytical predictions, where required.

The instrumentation for the CONE experiment subsystem consists of those sensors, status and position indication devices required to perform the following:

- insure the safety of the operation of the experiment subsystem;
- provide data and control capability necessary to conduct the on-orbit tests;
- provide data for demonstration/experiment analyses; and
- provide additional and redundant data both to enhance experimental analyses and obtain an understanding of the involved processes which in certain cases are only system demonstrations.

These devices will interface with an 8-bit data handling and processing equipment to the maximum extent possible without equipment modification.

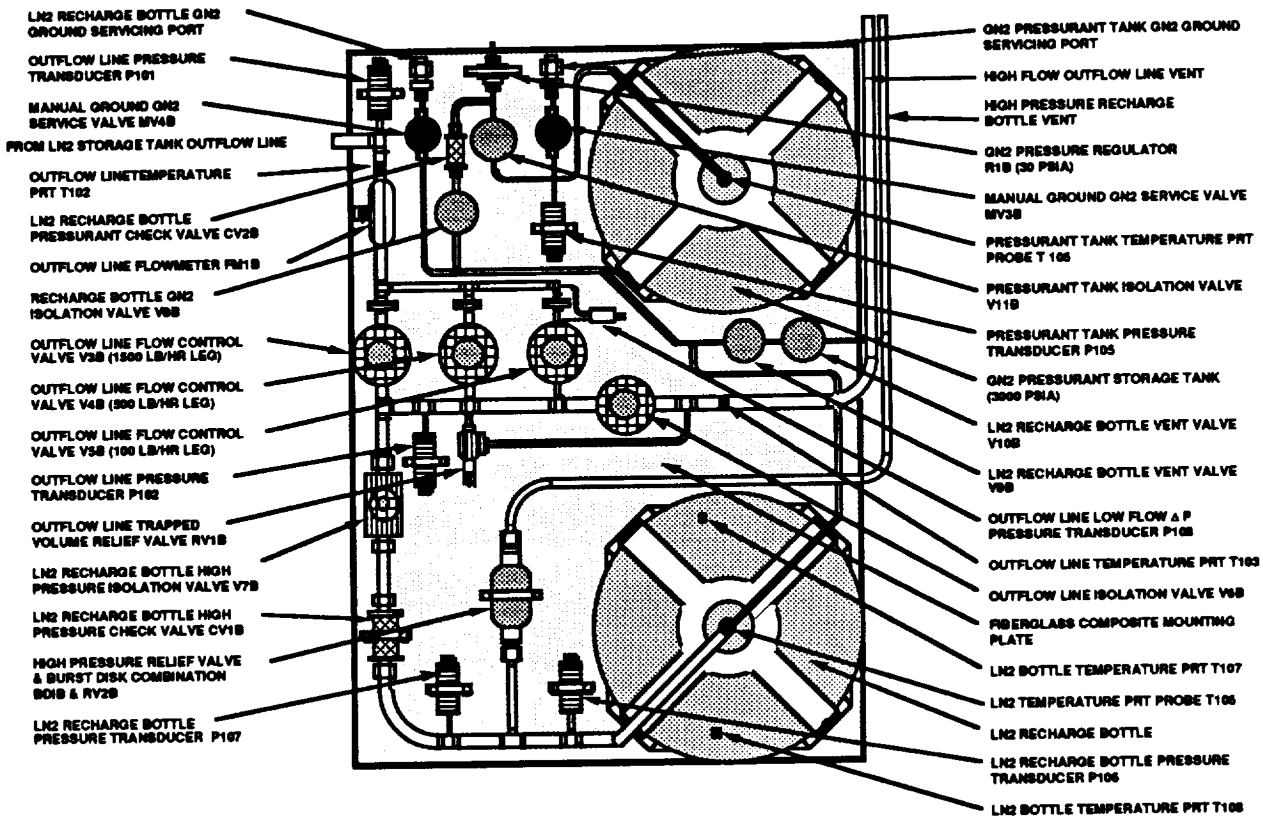


Figure 4.4-1 GN2 Pressurization and LN2 Bottle Recharge Module

Table 4.5-1 is a summary listing of the Experimental Subsystem Instrumentation. The PRD (Ref 4.5-1) contains a more complete listing where for each measurement an identification number is provided along with the function and location of the instrument. Range, accuracy, sample rate requirements, and resolution information (based on an 8-bit data word) are also provided.

<u>Redundancy Concept</u> - For the most part, no attempt has been made to duplicate transducers at a single location for redundancy purposes. Similar sensors are installed in close proximity to each other and are of sufficient numbers that a form of redundancy is provided. Loss of data from any single device will not result in the inability to complete experimental analyses or prediction verification or to accomplish required control functions.

Table 4.5-1 Experiment Subsystem Instrumentation List

INSTRUMENT ID	RANGE	SAMPLE RATE	NUMBER SENSORS	LOCATION	ACCURACY (±)
TEMPERATURE (°R)					
VAC JACKET/INSULATION	400-600,120-600	B	9	SUPPLY	1.0, 2.0
TANK WALL	120-170, 120-600	A	9	SUPPLY	0.5, 2.0
TANK/LAD/TVS/CHX FLUID	120-170, 120-600	A, B	23	SUPPLY	0.2, 2.0
SUPRT/PENTR/OUTLET	120-600	B	7	SUPPLY	2.0
VENT/PRESSURANT/ RECHARGE/OUTFLOW	120-600,400-600 120-170	B, A	10	OTHER	2.0, 10, 0.2
PRESSURE (PSIA)					
TANK	10-20, 15-30, 0-50	A	3	SUPPLY	0.05, 0.1, 0.5
TVS/CHX/VENT	0-50	B	3	SUPPLY/OTHER	0.5
STORED PRESSURANT	0-2000	B	1	OTHER	20
RECHARGE PRESSURANT	0-4000	B	2	OTHER	40
OUTFLOW LINE/REG GN2	0-50, 0-10 PSID	A	4	OTHER	0.5, 0.1
FLOWRATE (LB/HR)					
TRANSFER LINE FLUID	0-2000	A	1	OTHER	20 LB/HR
TVS/CHX	0-0.5, 0-10	B	2	SUPPLY	0.005, 0.1 LB/HR
QUANTITY GAUGING					
TANK FILL VOLUME	0-100%	A	1	SUPPLY	0.2 IN
LIQ/VAPOR POS DETECTOR	WET/DRY	A	5	SUPPLY	0.2 IN
ACCELERATION*					
3-AXIS ACCELERATION	1-500 μG	C	3	CARRIER	5.0 μG
POWER					
MIXER	0-5 W	B	1	PUMP PWR	0.05 W
SUPPLY TANK HEATERS	0-50W	B	2 ELMTS	HTR PWR	2.0 W
TVS/CHX FLOWMETER HTRS	0-100, 0-10 W	B	2 ELMTS	HTR PWR	5.0, 0.5 W
STATUS					
VALVE POS	OP/CLOSE	A	17	SUPPLY/OTHER	N/A

NOTE: SAMPLE RATES ARE CLASSIFIED AS FOLLOWS:
1 SAMPLE PER SEC = A, 1 SAMPLE PER 10 SEC = B
* 100 SAMPLE PER SEC = C (ACCELERATION TO BE PROVIDED BY AN EXTERNAL ACCELEROMETER PACKAGE)

Sensor Locations - Figure 4.1-1 provides an integrated schematic of the experiment subsystem defining locations for instrumentation.

Instrumentation Definition - The following sensors and instrumentation devices have been identified as having the proper characteristics to meet the data needs of CONE. Ref 4.5-1 & 4.5-2 contains additional information on each instrument.

Acceleration - SAMS is a self contained acceleration measurement system that will provide the acceleration data that can be correlated with the CONE measurements. The acceleration data is used to analyze free convection and liquid positioning. By use of the SAMS package, the CONE payload can use the Hitchhiker low rate data stream and avoid the use of a project recorder.

There are two versions of SAMS. One version is for the mid-deck area of the Shuttle and has 5 units made. The SAMS version for the cargo bay flies on Spacelab and is presently scheduled to fly once a year. Headquarters (Code-S) approval is required to fly this SAMS unit.

The cargo bay version of SAMS is at CDR at present. It will fly as the US Microgravity Payload (USMP) on the manifest. The cargo bay version flies on a cold plate. A peak power of ~200 watts with a continuous power of 125-130 watts is required. The SAMS is made up of two boxes and an adapter plate. Each box is approximately 2 feet by 1 foot by 1 foot. Each box weighs ~100 pounds.

The mid-deck version of SAMS is not close enough to the experiment to be useful, even though it is lighter in weight and is smaller in size, about the size of a mid-deck locker.

Liquid Nitrogen Density and Flow Rate - Transfer line LN2 flow rate of storage tank outflow will be measured using turbine Models FT designed and manufactured by Flow Technology. These units require 28 vdc power only to condition the output 0-5 vdc signal which is proportional to the fluid velocity over the flow range of the instrument. Two phase flow can be detected by a sudden change in the indicated velocity. Device accuracy is 0.3%.

Liquid service performance specifications are based on a liquid with a viscosity of 1.2 centistokes with ball bearings. A flow rate from 0.227 to 189,250 l/min (0.06 to 50,000 gpm) of liquid can be handled. The flowmeter can withstand temperatures down to LH2. The flowmeter has a magnetic or modulated carrier (RF) pickoff. LN2 calibration will be corrected to the referenced fluid and to the pressure and temperature conditions of the LN2 at the meter.

No delta qualification is required for the CONE applications.

Gaseous Nitrogen TVS/CHX/OHX Flow Rate - The GN2 flow rate from the LN2 storage tank thermodynamic vent system, compact heat exchanger and outflow heat exchanger will be measured using turbine units Model FT and HR designed and manufactured by Flow Technology. These units require 28 vdc power only to condition the output 0-5 vdc signal which is proportional to the flow range of the given instrument. Device accuracy is 0.05%.

Gas service performance specifications are based on a gas density of (0.075 lb/ft^3) (at standard temperature and pressure) with ball bearings. A flow rate from 0.0056 to 480 m^3/min (0.2 to 15,000 ft^3/min) in gas can be handled. The flowmeter can withstand temperatures down to LH2. The flowmeter has a magnetic or modulated carrier (RF) pickoff. Prior to fluid introduction to the flow meter it will be heated to 222 K (400 R) so that consistent conditions are maintained to the device.

No delta qualification is required for the CONE applications.

Flow Meter Electronics - Each flow meter contains an electronics unit with the following characteristics:

• Manufacturer - Flow Technology, Phoenix, AZ.
• Part No.. - RC 52 Rate Converter with pulse scaling
• Use - As a signal converter with the frequency scaled to provide a pulse output in engineering units
• Standard Output - a frequency to voltage conversion
with a 0 to 10 vdc output (optional: 0 to 5 vdc); Current -
4 to 20 ma; linearity of .01% typical, 0.1% max
• Enclosure: NEMA 4 with MS connectors
Explosion proof, class 1 group D or B
• Power Supply - 24 V (22 to 32 Vdc), 180 mA max -- 5.04 watts
• Input Signal - magnetic pickoff, 0 to 10k Hz, 20mV to 10V
Modulated carrier pickoff 0 to 3500 Hz signal, 445 KHz carrier frequency; Pulse -- 0 to 10 KHz, 3.5 to 32V
• Temperature - Operating and storage-
-40°C to + 85°C (-40°F to + 185°F)

Temperature - All temperature sensors will be Rosemount Model 118MF2000C four-wire Platinum Resistance Thermometers (PRT). PRT's will be excited from 10 ma constant current sources. Three full scale temperature ranges 67 to 95 K(120-170 R), 67 to 333 K (120-600 R), and 222-333 K (400-600 R) cover all desired experimental data needs. The 67 to 333 K(120-600 R) range will be split into two equal parts to maintain desired accuracy. Special signal conditioning between the sensor output and the data handling unit is provided by the data handling unit.

Pressure - The pressure transducers selected for the experiment subsystem is the basic variable reluctance unit designed and built by the Tavis Corporation. The unit operates with a 28 vdc input and provides an output of 0 - 5 vdc which is linear within the pressure range of the unit. In some locations temperature limitations on sensor electronics requires a modification which removes the electronics away from cryogenic temperature extremes.

Differential Pressure - This pressure sensor operates from room temperature down to -272°C and has a range of 207 kN/m^2 differential (30 psid) for determining the flow rate in the 45 kg/hr (100 lb/hr) flow leg of the outflow line. These sensors are based on a silicon piezoresistance sensing element which produces low hysteresis, nonlinearity, and nonrepeatability. The sensor power dissipation is less than 6 mW. The sensor is precalibrated at cryogenic temperatures.

Liquid Level & Liquid Detection - The settled LN2 liquid level will be determined in the LN2 storage tank by a super conductor type of probe that is compatible with surface tension and wicking characteristics of LN2 in a low-g environment. These sensor systems are a development item. The actual tank fluid quantity will be determined by tank geometry with respect to the sensor location and the expected interface shape based of the acceleration environment..

Point liquid detection will be determined with a liquid/vapor point sensor. These warm wire sensors are basically a platinum thermometer to which a controlled current is applied. If the sensor is dry, self-heating generates enough temperature that resistance increases significantly. This resistance change is then converted so that a discrete 28 vdc signal represents the dry state, while 0 vdc indicates wet.

4.6 Component Assessments

Components, parts and materials used in CONE are summarized in Ref 4.5-2.

4.6.1 Experiment Components

This section addresses all of the component equipment required for the Experiment Subsystem. The components defined below are the initial selection based upon current CONE requirements. They are based upon the existing design maturity of the various components and their capability to perform required functions with minimum modification and the greatest potential for use with LN2 and the environment of the Orbiter cargo bay.

Pressure Regulator - Sterer Engineering now a division of Vickers has been designing, manufacturing and qualifying aerospace valves and related components for over 30 years. Their design for the pressurant regulating valve for CONE is based on this experience and the specific design utilized on the Manned Maneuvering Unit (MMU) regulator, which they developed. The MMU regulator was required to reduce 24800 kN/m^2 (3600 psig) to 1460 kN/m^2 (212 psig) with an output tolerance of ±103 kN/m^2 (±15 psi) while flowing GN2 at 1.2- 3.7 m^3 (42-132 standard cubic feet per minute). The regulation tolerance applies to the GN2 outlet pressure throughout the inlet pressure range and the GN2 temperature range of 205-338° K (370-610° R). The CONE application has an output of 207±14 kN/m^2 (30±2 psia) and will require modification and Δ qualification.

Motor Operated Ball Valve - This valve (Model 5D163) was developed for use in airborne research and development for a sector of the Star Wars program (SDI).

Motor valves are available from 12 to 115 VDC. When connected to an optional electronics interface package, the valve can be positioned by thermocouples/RTDs and/or a 4 to 20 milliamp generating source, which makes the valve ideal for use as a temperature control/mixing device, and/or as a regulating or flow control unit.

Burst Disc/Relief Valve Assembly - This valve (PN 1113-505) was developed for and flew on both the Viking and Apollo programs by Ketema. The valve design allows for the tailoring to specific burst and relief pressures and required flow rates. The relief and burst features of this valve are in series. For CONE these values will be 345 kN/m^2 (50 psia).

This component will be required to complete a delta qualification program in order to meet the CONE environmental requirements.

Check Valve (200 series) - This check valve does not leak at any differential pressure. At extremely low differential pressure, it is quick opening. Opening pressures are as low as 0.1 psi. The poppet closes at zero flow before the return flow starts. The "0" ring absorbs shock and automatically compensates for normal wear. The spring retainer ports allow full flow even when the surge pressure forces the poppet against the stop. Minor expansion and contraction of the "0" ring absorbs shock and hammer affects. Foreign particles in the fluid stream do not prevent proper seating. The valve can withstand temperatures down to LN2. No special wear-resisting materials are required. All valves are marked with an arrow to indicate the direction of flow.

No delta qualification is required for CONE applications.

JT Flow Expander (visco jet PN: JEVA18555470) - The visco jet incorporates increased minimum passage sizes for corresponding Lohm rates, with the advantage of reducing cavitation and minimizing the possibility of clogging due to contamination. 92 Lohm rating is available from stock. Coverage from 3700 to 313,000 Lohm range in 5% increments is available.

The visco jet has bidirectional flow calibration with filter screen protection and viscosity compensation. Flow tolerances of ±5% and ±10% are available. It has a 3000 psi maximum working pressure differential. Construction is brazed and vacuum diffusion bonded, with no threads or elastomers.

JT Expander (visco jet PN JEVA1825800H) - An independent visco 'stage' consists of three different patterns which are combined to form a complex fluid passageway. The visco jet contains a large number of spin chambers and tangential slots arranged in a series to provide a uniquely restrictive, tortuous path for the fluid medium. Flow enters each stage at the center of the pattern. From that point, it passes into a spin chamber via a rectangular slot. Within the chamber, the spinning liquid creates a back pressure which varies with the viscosity of the liquid. The liquid then passes through a restriction with a circular cross-section to the center of another spin chamber on the opposite face of the 'stage'. This spin chamber has an exiting tangential slot which is in the opposite direction from the previous entrance slot. The change in direction forces the liquid to come to rest before it makes its exit from the deceleration chamber. This process is repeated within all the series of cavities of one 'stage' until the liquid leaves through the final circular cross-section hole at the center of the pattern.

Liquid flowing through any orifice will cavitate whenever its velocity causes the pressure in the throat of the orifice to drop below the vapor pressure of the flowing liquid. Even though there may be a high supply pressure and a high back pressure on an orifice, if the velocity is high enough there will be a subsequent lowering of the pressure in the throat of the orifice and the possibility of cavitation. The effects of cavitation are unstable flow and erosion. To prevent cavitation, the throat pressure must be maintained by applying sufficiently high back pressure or reducing the velocity of the liquid as it flows through the restrictor. Series restrictors lower the velocity.

Flow Expander - JT 3 (PN: JETA 1872300D) - This Lee Jet is a miniature filtered fixed resistor jet. Each contains a calibrated orifice, two matched filter screens so that bidirectional flow is available, and reliable locking and sealing devices. The restrictor is small in size, light weight, and has proven reliability.

Latching Torque Motor Valve - The Eaton latching torque motor valve (PN 48004300) is used for fluid isolation, with medium flow. Similar valves have flown on COBE, TDRSS, FLTSATCOM, GPS and GOES satellites.

The valve is contamination resistant. It has stable back pressure relief with no sliding fits or inlet and outlet filters. It has a Teflon inset poppet of all-CRES construction. The poppet is spring loaded.

Delta qualification is required for CONE environments.

Manual GN2 Service Valve - The GN2 pressurant storage tanks will be loaded through high pressure service valves provided by Pyronetics devices a subsidiary of OEA. This valve utilizes a metal-to-metal poppet/seat design wherein the internal pressure within the system tends to assist seating the poppet. This valve also incorporates dual seals and the potential for three independent seals, if necessary. This design is utilized on many high pressure gas systems as well as storables. The valve materials are basically CRES with the seat being 15-5 PH. All seals are Teflon or KEL-F. These valves will be similar to those qualified for use on the MARK II Propulsion Module (MMAG) per PD 4700212. These valves will require a redesign for cryogenic applications if used for the LN2 fill and vent ports which may involve a bellows type diaphragm followed by a delta qualification program to meet CONE environmental requirements.

Mixer pump - The operating conditions and requirements for the LN2 mixer pump are best met with a partial emission type pump driven by an induction motor fed from a variable frequency power source. This configuration provides for efficient matching of the pump capabilities to any desired flow operation level of the system. By varying the pump and motor speed through a variable frequency drive, the pump and motor can be operated at their best efficiency at all times and power is not wasted in throttling devices to achieve a desired system flowrate. A single pump design can perform the high and low flow mixing functions since the range of flow rates and associated head rise covers the range required to mix the storage tank contents at various fill levels to attain the required flow regimes. This approach together with appropriate component design also provides the greatest reliability achievable.

A pump and motor design approach provides the features and reliability required for this cryogenic application. A 3-phase induction drive motor is short coupled to the pump without the need for seals since the unit is submerged. The motor shaft is mounted on preloaded ball bearings with the pump impeller cantilevered from one end of the shaft. The partial emission pump is equipped with a screw type inducer to further enhance its capability to operate at very low net positive suction heads (NPSH). Prior cryogenic experience has verified this performance and has also demonstrated the capability of the pump to move vapor. The partial emission pump configuration was selected over a full emission design because it allows for a lower NPSH requirement with only a 10% loss in pump efficiency. This pump utilizes existing technologies and is based on Barber-Nichols designs currently in operation. The pump design is greatly simplified by locating it within the tank. Further information is contained in this section on pump characteristics.

Orifice assembly (Type E) - Orifices are cleaned , inspected and flow tested before shipment from the vendor. It is important to have the assembly cleaned so that physical contaminants do not obstruct flow through the orifice. The orifices are suitable for flow in either direction. They have high pressure capability with a predicted flow rate for repeatable orifice sizes and shapes. Accurate throttling results with precision flow restriction.

The orifice is a one piece construction of solid metal. Sizes range from 0.015 to 0.32 cm (0.006 to 0.125 inches) orifice diameter.

No delta qualification is required for CONE applications.

Pilot valve (400 Series) - Main and pilot poppet valves are pressure seated normally closed. When energized, the solenoid unseats the pilot poppet allowing flow through pilot passages to exhaust at the valve outlet. The restricted pilot metering orifice causes pressure drop across the main poppet forcing it to open. Pilot exhaust into the venturi section assures full opening at low pressure drop conditions. De-energizing the solenoid returns the main poppet to its normally closed position.

The Straza Series 400 cryogenic and high temperature solenoid valves are designed specifically for pneumatic high pressure/high flow capacity applications over a temperature range down to LH2.

Pilot operation allows actuation at high pressure with no sacrifice in weight. Streamline flow-through configuration eliminates the need for 'sizing up' to achieve full line size flow capability. Zero leakage characteristics at up to 60 G's has been achieved by use of pressure sealed poppets combined with contained Mylar and Kel-F seats.

No delta qualification is required for CONE applications.

Port (vacuum seal off valve) - The vacuum seal-off valves are designed for vacuum closure. The V-1046 is a 1 inch valve and can serve as pump-out and isolation valves as well as safety relief devices. The valve is made of aluminum with welded installation, with two seals.

Delta qualification is required because of the need for redesign of the interior/spring for space environment.

High Pressure Gas Service Latching Valve - The latch valve has an unbalanced poppet, therefore as the inlet pressure increases, the seating force increases proportionally. The unbalance force is aided by a spring that assures adequate seating force even when the unit is unpressurized. In the open (latched) position, the force from the magnet is adequate to hold the valve in the open position without assistance from the solenoid energized electromagnetic field. To close the valve, the permanent magnetic field is decreased by introducing an electromagnetic field of opposite polarity of sufficient force to permit the spring to close the valve. Thus, the valve is opened or closed with short duration electrical impulses. Continuous application of power is not required to maintain the valve in either position. The position indicator switch is magnetically operated by the position of a small permanent magnet that is an integral part of the poppet., thus obtaining a true indication of the poppet position. Extremely low leakage are obtained using fusion welding and a vacuum remelt bar stock for the valve body. This valve, manufactured by Consolidated Controls, is flight qualified.

4.6.2 Materials Assessment

Three incompatibilities were identified in the material review.

Aluminum - All alloys were rated B in corrosion resistance. This is rectified by specifying appropriate coatings for all exposed surfaces. All aluminum surfaces will be coated on CONE.

CRES 17-4PH - The body material for the high pressure isolation valve is made from this material which is rated B in stress corrosion cracking resistance. It may be possible to obtain a material usage agreement (MUA) permitting this material because the valve will only be cycled twice. If this is not possible, then the vendor may be able to make the valve from another alloy. If this is not possible, the valve could be replaced with a slower acting ball valve.

Most Non Metals - Most non-metals were listed as untested in MSFC-HDBK 527C. Further research may reveal that some of the materials have been tested. Otherwise, the materials will be tested for the appropriate parameters.

4.7 Experiment Analyses

Over the duration of the CONE design study numerous detailed analyses were conducted to provide validation the experiment subsystem design effort and to characterize the required CFM processes under investigation or those that are ancillary support processes.

4.7.1 Liquid Storage

Storage Tank Insulation Trade - Figure 4.7.1-1 describes the trade study on whether that tank must be vacuum jacketed or if it could use a more conventional insulation system such as foam. The required thermal performance was that the boiloff must be less than 0.14 kg/hr (0.3 lbm/hr), which is the maximum boiloff that would allow for a 10 day hold. A parametric analysis was performed to determine the boiloff of different amounts of foam thicknesses. The maximum practical thickness of foam was set at three inches due to handling concerns. As the chart shows the required boiloff cannot be achieved with 7.6 cm (3 inches) of foam, therefore the tank must be vacuum jacketed.

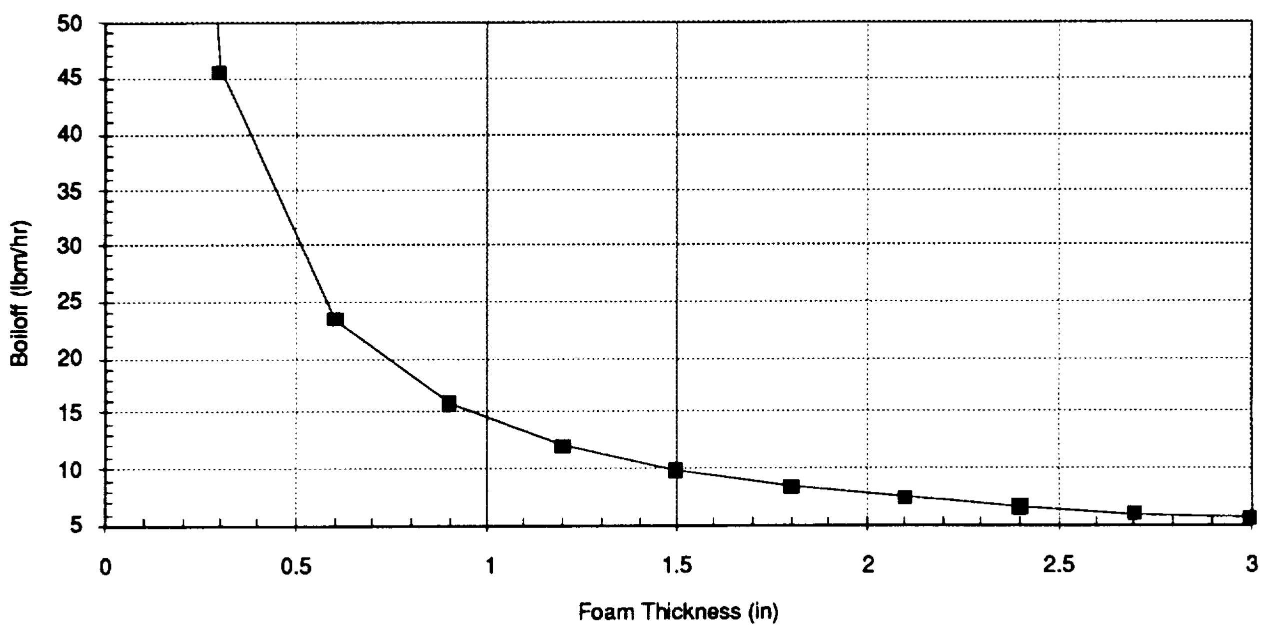


Figure 4.7.1-1 Storage Tank Insulation Trade

Storage Tank Thermal Analysis - This analysis consisted of performing multiple runs with different amounts of MLI, until the required tank heat flux of 1.4 w/m^2 (0.45 Btu/hr-ft^2) was obtained. The runs used the predicted nominal vacuum jacket temperature of 278.6 K (501.5 R) corresponding to the attitude of earth facing with the Orbiter bay doors open. Two support strap options were considered because the tank dynamic analysis used to size the straps was not completed when the thermal analysis was performed. Both options were analyzed and found to be capable of achieving the desired heat flux. Option 1 required 0.76 cm (0.30 inches) of MLI, which is 15 layers for a layer density of 20 layers/cm (50 layers per inch). The MLI lay-up used in the analysis was Double Aluminized Mylar with Double Silk Netting. The second option required 1.17 cm (0.46 inches) of MLI, which is 23 layers. The tank dynamic analysis was subsequently completed and it was found that the thicker strap size (Option 2) was required to meet storage tank stiffness requirements. Therefore, Option 2 represents the baseline storage tank thermal performance. Option 1 is included to demonstrate how a thinner strap affects the different heat leak components.

Table 4.7.1-1 presents the resultant heat leak and the percent contribution due to each heat transfer path. Option 1 has ~33% of the heat leak being due to conduction, which is a reasonable value for such a small tank. Option 2,though, has ~56% of the heat leak due to conduction. This is a large percentage but will not have much affect on the test results. The stratification tests will have an elevated heat leak 42 w (144 BTU/hr) therefore the amount due to conduction will be very low. The mixing and active pressure reduction tests will have a great amount of fluid motion, thus the hot spots will not affect the results. Only the TVS tests will be affected, but since the tests are a demonstration, the effect will not be very important.

Table 4.7.1-1 Storage Tank Thermal Analysis

- **OPTION 1: STRAP A/L = 1.75E-02 FT**
- **OPTION 2: STRAP A/L = 5.31E-02 FT**

	Option 1 (15 layers MLI)		Option 2 (23 layers MLI)	
Type	Heat Leak (BTU/hr)	% Total	Heat Leak (BTU/hr)	% Total
MLI	6.00	67.2	3.96	43.6
Straps	1.08	12.1	3.27	36.0
Plumbing	1.43	16.0	1.43	15.7
Wiring	0.43	4.8	0.43	4.7
Sum	8.93	100.0	9.07	100.0

J-T Expander Trade - A trade study was performed to select the J-T expanders for the various heat exchangers. The issues are discussed below.

Development status - Viscojets are available in a wide range of sizes and capabilities. Regulators or temperature compensated expanders are not as mature in their design as viscojets. Viscojets are preferred.for this issue.

Complexity - Viscojets are simple flow restrictions with no moving parts. Regulators and temperature compensated expanders are considerably more complex. Viscojets are preferred for this issue.

Cost - Viscojets are certainly less expensive than the other J-T expanders.

Clogging Susceptibility - One of the principal concerns with viscojets is their susceptibility to clogging. This has been a motivation to consider other expanders. MMAG has successfully demonstrated the use of a regulator as a J-T expander during IR&D tests. Regulators, therefore, have an advantage over the other expanders. This advantage is not a discriminator, however, because the J-T expanders in CONE will all be downstream of a fine mesh screen which has a considerably smaller pore size than the viscojet. Therefore, all relatively large solid contaminants should be filtered upstream of the expander and the viscojet should not suffer any clogging.

Variable Flow Rate - The regulator and temperature compensated expander can accommodate a wide range of flow rates and both of them have an advantage over the viscojet. CONE does not require a wide range of flow rates, however, so the limited range of flow rates through a viscojet is adequate for the mission.

Flow Predictability - The viscojet permits a simple relationship between flow rate and ΔP across the expander. The regulator and temperature compensated both have variable flow areas, so the flow rate is not predictable if the ΔP across the expander is known. Viscojets are preferred for this issue.

Future Applicability - Viscojets are preferred for future LN2 and LO2 usage due to their demonstrated performance in ground tests. Regulators or temperature compensated expanders are considered fallback components for use with other cryogens.

Based on these results, viscojets were chosen for the CONE J-T expanders. Table 4.7.1-2 documents the J-T expander trade.

Fixed Restriction Affect on TVS Conditions - The effects a fixed restriction has on the downstream conditions were assessed by considering different flow rates through an 80,000 Lohm J-T expander. Figure 4.7.1-2 shows the pressure and temperature difference across the J-T expander for several passive TVS flow rates. The most significant aspect of the figure is the rapid decrease in ΔT across the expander as the flow rate is decreased. The decrease in ΔT represents a decrease in heat transfer potential between the heat exchanger and the surrounding fluid, assuming that the heat exchanger fluid is drawn from the surrounding fluid. The decreasing heat transfer potential results in decreased heat transfer and a shift in the dry out point downstream as shown in Figure 4.7.1-3, even though the heat exchanger external film coefficient, which limits heat transfer to the heat exchanger fluid, remains unchanged. A point is reached with decreasing flow where all of the fluid is not vaporized and the full cooling capacity of the heat exchanger is not utilized. As a consequence of the variation in downstream conditions, it is impractical to design a fixed J-T expander heat exchanger with large variations in flow rates. Relatively small flow variations, however, can be accommodated.

Table 4.7.1-2 J-T Expander Trade

ISSUES	VISCOJET	REGULATOR	TEMPERATURE COMPENSATED EXPANDER
DEVELOPMENT STATUS	EXISTING	NEW	MODIFICATION OF EXISTING DESIGN
COMPLEXITY	LOW	HIGH	MODERATE
COST	LOW	HIGH	HIGH
CLOGGING SUSCEPTIBILITY	ACCEPTABLE VISCOJET: 125 MICRON SCREEN: 10 MICRON	LOW	MODERATE
VARIABLE FLOW RATE	LIMITED BUT TOLERABLE	WIDE RANGE	WIDE RANGE
FLOW PREDICTABILITY	HIGH	LOW	LOW
FUTURE APPLICABILITY	PREFERRED FOR LN2	FALLBACK	FALLBACK

DISCRIMINATOR

ADVANTAGE

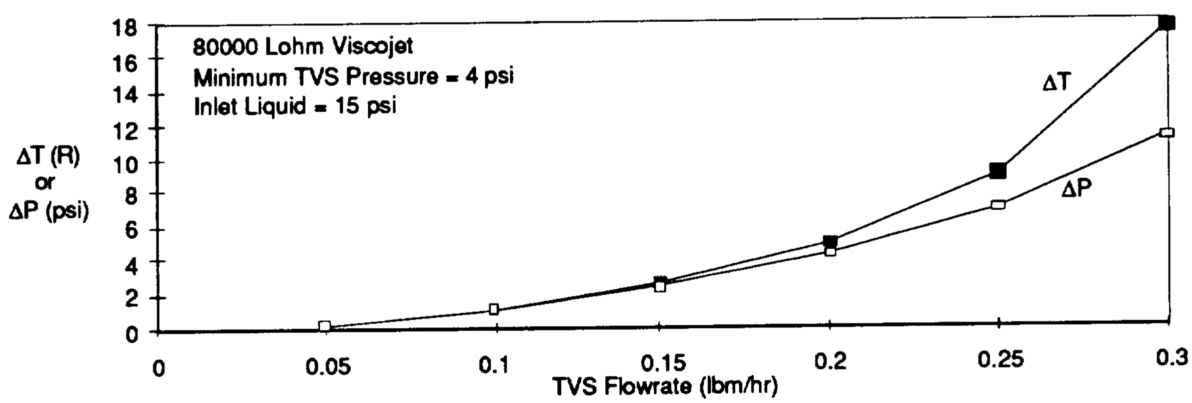


Figure 4.7.1-2 Fixed Restriction Effects in TVS Conditions

TVS Flow Rate Selection - TVS flow rate of 0.14 kg/hr (0.30 lbm/hr) was based on the flow rate required to compensate for the high liquid storage demonstration heating rate of 5.3 w (18 Btu/hr) with a 50% margin. The TVS was not designed for multiple flow rates because of J-T expander flow rate restrictions.

Passive TVS Performance With Different Heat Transfer Regime - The performance of the passive TVS was characterized under different heat transfer regimes to evaluate the sensitivity of TVS performance to external heat transfer. This assessment was performed because there is little information regarding heat transfer on the orbiter. Three cases were considered: 1) free convection based on orbiter drag acceleration and heat exchanger geometry, 2) free convection limited to a minimum Nusselt number of 5, and 3) conduction from the heat exchanger outer surface to the bulk liquid. The limited Nusselt number case was based on free convection heat transfer data from the Orbital Refueling System (ORS) demonstration which indicated a minimum Nusselt number = 5. Simulations were performed to evaluate the effect of the different heat transfer regimes on an 80% full case with 1.4 w/m^2 (0.45 BTU/hr-ft^2) heat flux with no contact between the ullage and the tank wall. The results are shown in Figure 4.7.1-4. The convection cases overlap following an initial larger pressure slump with the Nusselt number = 5 case. The conduction case, however, shows diminished pressure reduction capability. The diminished capability resulted from incomplete utilization of the cooling capacity of the heat exchanger.

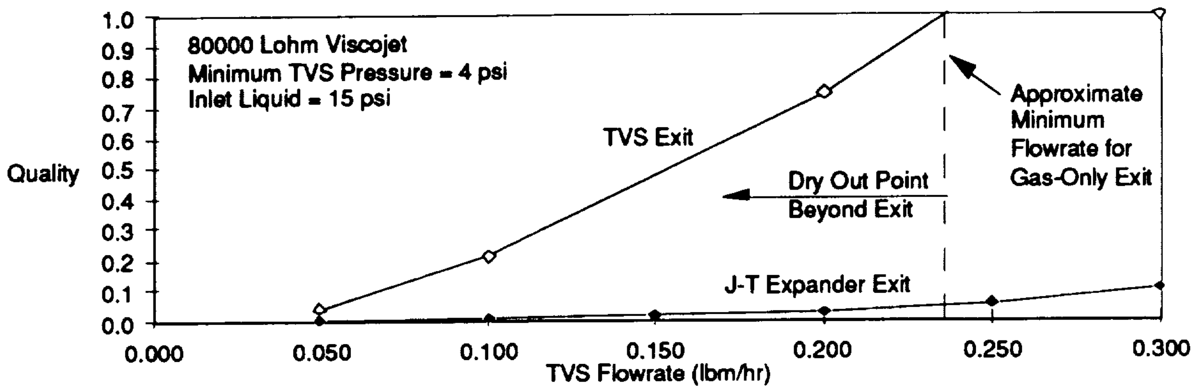


Figure 4.7.1-3 Fixed Restriction Effects on HX Entrance and Exit Qualities

Conditions in the TVS heat exchanger for the three external heat transfer cases were also evaluated in the analysis presented above. Figure 4.7.1-5 illustrates the quality in the heat exchanger as a function of distance from the inlet. The quality increases linearly until all liquid is vaporized and then remains equal to 1 thereafter. The convection cases experienced complete dryout whereas the only about half of the liquid was vaporized in the conduction case. Thus, only half of the cooling capacity of the passive TVS was utilized with conduction heat transfer. The quality plot also indicates that the heat exchanger dried out earlier with the limited Nusselt number case than with the convection case based solely on acceleration and tube geometry. This indicates that the external heat transfer was actually higher with the limited Nusselt number case than with the other convection case. The minimum heat transfer occurring on ORS corresponds to the maximum heat transfer case of this analysis. These observations are confirmed by the temperature and heat transfer plots presented in Figure 4.7.1-6 and -7. The temperatures remain constant until the dryout occurs and then increase to the ambient temperature. The heat transfer summations increase at approximately a constant rate until dryout occurs and then level off as the heat transfer rate decays. This analysis shows that the heat exchanger has adequate length to ensure complete utilization of the heat exchanger cooling capacity of the external heat transfer. It is doubtful that the conduction case is realistic due to the magnitude of known orbiter accelerations and the fact that the ORS demonstration indicated higher heat transfer rates than would be expected from free convection.

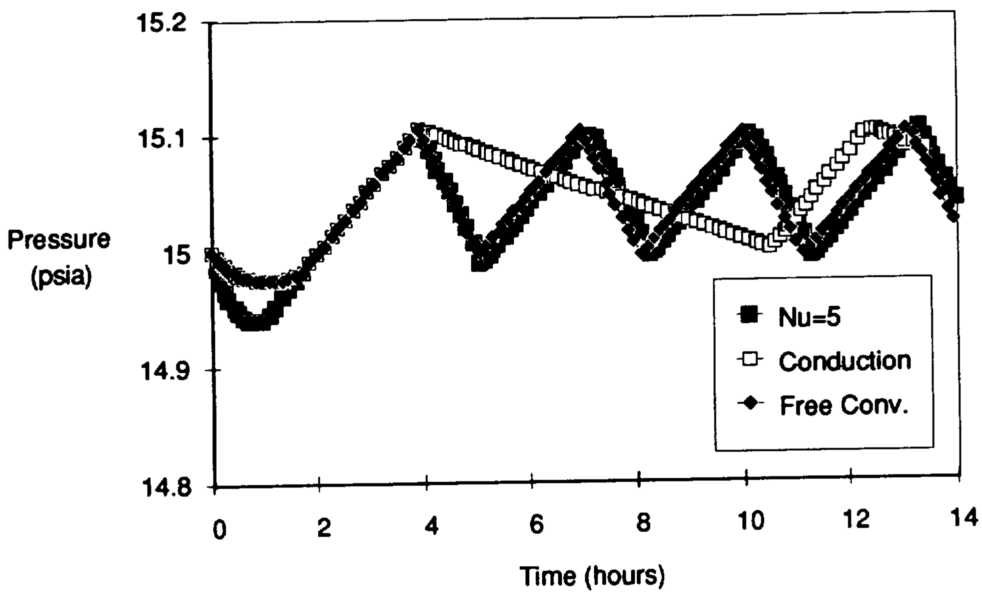


Figure 4.7.1-4 Passive TVS Performance with Different Heat Transfer Regimes

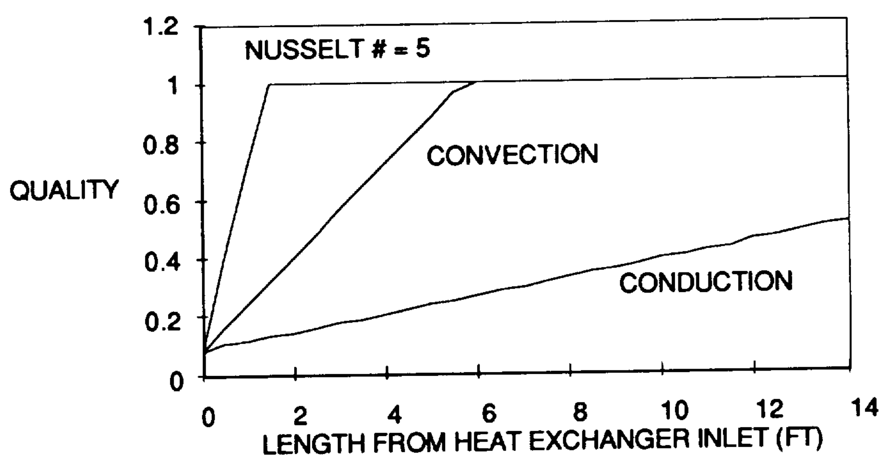


Figure 4.7.1-5 Exit Quality with Different Heat Transfer Regimes

4.7.2 Liquid Supply

Nominal Outflow Analysis - Table 4.7.2-1 presents a summary of the nominal outflow analyses to determine the impact that these operations will have on the Orbiter interfaces. The liquid outflow analysis model presented during the Concept Review (CR) was used to determine the values presented in the table. Different size exit orifices were parametrically investigated to determine which size should be used. The table shows that the orifice must be between 1/4 inch and 3/16 inches in size. From this data the recommendation of having a 1/4 inch exit orifice was made. The table also shows that the resultant thrust on the Orbiter is very low, even with the fairly high velocities that the flows will have. Therefore, the fluid will likely leave the area of the Orbiter without imparting any appreciable momentum onto the Orbiter.

C-2

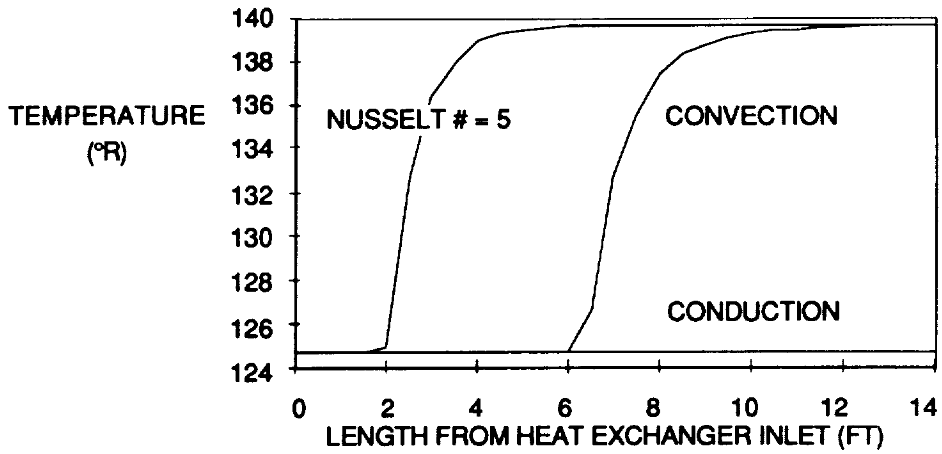


Figure 4.7.1-6 Heat Exchanger Temperature with Different Heat Transfer Regimes

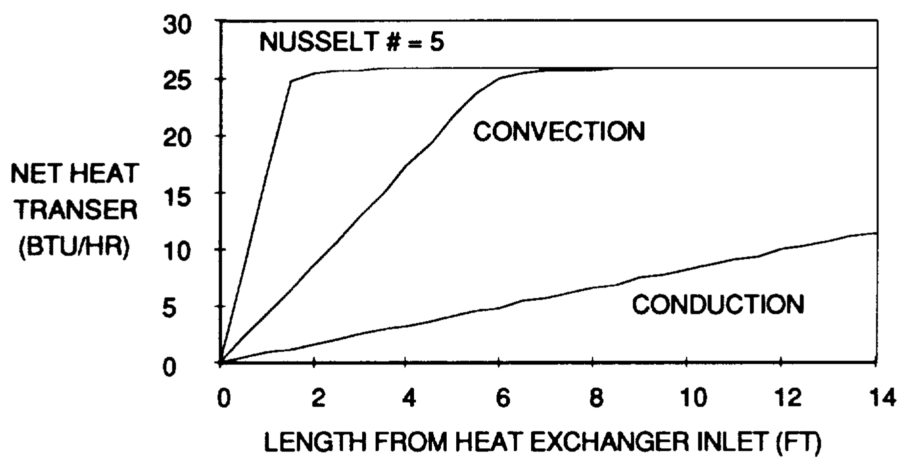


Figure 4.7.1-7 Cumulative Heat Transfer with Different Heat Transfer Regimes

Pressurization Sizing - The pressurization and outflow analysis indicated that 4.8 kg (10.6 lbm) of GN2 will be required for the two expulsion tests. Both tests expel 40% of the tank contents, but the first expulsion at 45 kg/hr (100 lbm/hr) consumes more pressurant than the second at 227 kg/hr (500 lbm/hr) due to the lower flow rate. This lower flow rate allows more time in the tank for condensation of pressurant. Consequently, the first expulsion requires more than twice the amount of gas as the second expulsion. The initial conditions used in the analysis were 20.7 MPa and 294 K (3000 psia and 530 R) and the final conditions were 0.7 Mpa and 267 K (100 psia and 480 R). With a $\Delta\rho$=1.04 kg/L (13.42 lbm/cubic foot), the usable amount of gas which can be loaded into one tank is 4.7 kg (10.4 lbm), so more than one tank is required. This was accomplished by loading the recharge bottle and linking it to the pressurization system. This permits using the gas from the recharge bottle for the first expulsion. One consequence of this pressurization scheme is that the first recharge test must be performed following the first outflow demonstration. The recharge was performed at the beginning of the first outflow at the Concept Review. Moving the recharge to the end of the first outflow resulted in the addition of a thermal conditioning step between the outflow and recharge demonstrations to lower the LN2 temperature. Such a step was necessary to inhibit flashing flow in the transfer lines. Consumption is driven by the relatively high interface heat transfer resulting from the ORS recommendation of a Nusselt number of 250.

Table 4.7.2-1 Nominal Outflow Analysis

		Exit Conditions at Flow Rate of 500 lbm/hr				Exit Conditions at Flow Rate of 100 lbm/hr			
Orifice ID (in)	Max Flow (lbm/hr)	Exit P (psia)	Velocity (ft/sec)	Thrust (lbf)	Quality	Exit P (psia)	Velocity (ft/sec)	Thrust (lbf)	Quality
0.1875	334.5	Cannot Achieve this Flow Rate				5.14	101.8	0.230	0.0721
0.25	594.7	13.0	27.3	0.756	0.0122	2.95	127.6	0.255	0.1025
0.3125	929.3	8.80	65.5	0.958	0.0418	1.91	142.0	0.270	0.1201
0.375	1338.0	6.31	89.9	1.085	0.0633	Exit Pressure Below Triple Point			

<u>OHX Flow Rate Selection</u> - OHX flow rate was determined from hardware simplification consideration. The single phase flow rate for OHX testing was reduced from 907 to 45 kg/hr (2000 to 100 lbm/hr). This permitted reducing the 2-phase side flow rate accordingly. The maximum flow rate was about 4.5 kg/hr (10 lbm/hr), which was limited by triple point conditions. The flow rate was close to the sum of the two CHX flow rates as described later in this section, so the subsystem concept was modified so that the OHX could use the CHX flow control orifices. This eliminated separate OHX flow control orifices, valves, flow meter, and distribution.

<u>CONE Experiment Planned and Contingency LN2 Tank Outflow Paths</u> - An analysis demonstrated the capability of the experiment subsystem design to get liquid out of the LN2 storage tank. This capability is defined by the following priority:

- The primary outflow path for the tank is to bypass the OHX and flow into the outflow line via valve V1. Either the 45 or 227 kg/hr (100 or 500 lbm/hr) outflow flow control (V5B or V4B, respectively) can be selected for the desired rate which is routed to the high flow vent via valve V6B.

- If subcooling is desired (or due to a closed failure of valve V1) tank outflow fluid is routed through the OHX and into the outflow line. Normally the 45 kg/hr (100 lbm/hr) flow control would be used, but the 227 kg/hr (500 lbm/hr) can also be accommodated at a much lower subcooling rate. The 682 kg/hr (1500 lbm/hr) results in excessive pressure drop and would only be used in extreme situations that require multiple component failures.

- If tank fluid cannot be routed through the outflow line (valve V6B failed close) the OHX two phase side can be operated at a flow of 4.1 kg/hr (9 lbm/hr) to deplete the tank contents. It would take over 40 hrs to drain the tank in this mode and would only be used for contingency.

- An additional option for a failed valve V6B is to route the fluid through the recharge bottle plumbing.

- A final option is to empty the tank by opening the tank vent (valves V15A and V16A).

See Figure 4.1-1 for the flow schematic.

CONE Experiment LN2 Tank Planned and Contingency Pressure Control Paths - An analysis demonstrated the capability of the experiment subsystem design to control pressure in the LN2 storage tank. This capability is defined by the following design features:

- The primary TVS flow path is capable of maintaining tank pressure at an ambient tank heat leak and with the tank heaters at the low power setting.

- The CHX can be operated at two flow rates that remove 40 to 50 times the ambient heat leak and will control/reduce tank pressure when the tank heaters are on. The high power heater case dumps 16 times the ambient heat leak into the tank.

- The contingency mode of controlling tank pressure is to open the tank vent valves (V15A & V16A). The orifice in the line will control venting to a predetermined rate.

- Dual mechanical burst disks and relief valve combinations provide a last line of pressure control defense.

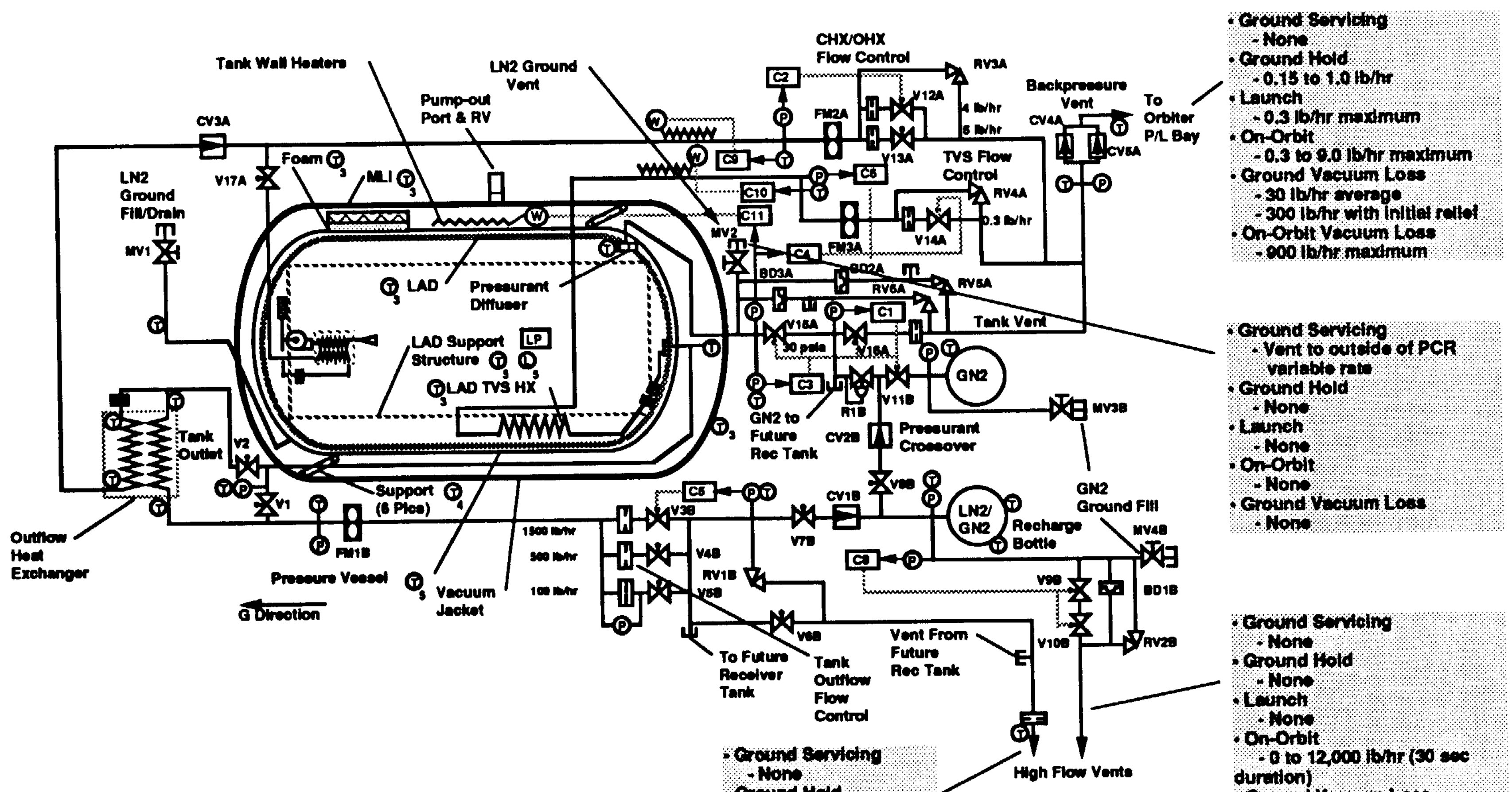
- Turning on the mixer pump will temporarily control/reduce tank pressure but it does not control the basic cause of pressure rise nor is energy removed from the tank using this technique.

It should be noted that the LN2 storage tank is very inert from a thermal standpoint and allows sufficient time margin on-orbit to react to anomalous operation. With the tank wall heaters on the highest power setting (40 w) it takes hours for tank pressure to increase.

Loss of vacuum of the ground can only be countered by the mechanical relief design.

CONE Experiment Subsystem Venting - Figure 4.7.2-1 shows the experiment subsystem venting scenario during various mission phases. Four modes of experiment subsystem venting are summarized as follows for both nominal and off-nominal cases:

• Backpressure In-Bay Vent			
- Nominal	0.14, 1.8, 2.3, or 4.1 kg/hr (0.3, 4,5 or 9 lb/hr)	- Effluent State	Warm Gas
- Maximum	136-409 kg/hr (300-900 lb/hr)	- Effluent State	Liquid
• LN2 High Flow to Space Vent			
- Nominal	45-227 kg/hr (100-500 lb/hr)	- Effluent State	Liquid
- Maximum	227 kg/hr (500 lb/hr)	- Effluent State	Liquid
• GN2 High Flow to Space Vent			
- Nominal	0-727 kg/hr (0-1600 lb/hr)	- Effluent State	Warm Gas
- Maximum	727 kg/hr (1600 lb/hr)	- Effluent State	Warm Gas
• LN2 Ground Vent			
- Nominal	TBD	- Effluent State	Cold Gas
- Maximum	TBD	- Effluent State	Liquid



Cold	STP
1 lb/hr = 0.066 cfm 10 lb/hr = 0.66 cfm 100 lb/hr = 6.6 cfm 1000 lb/hr = 66 cfm 10000 lb/hr = 660 cfm	1 lb/hr = 0.23 cfm 10 lb/hr = 2.3 cfm 100 lb/hr = 23 cfm 1000 lb/hr = 230 cfm 10000 lb/hr = 2300 cfm

Figure 4.7.2-1 Experiment Subsystem Venting Summary

4.7.3 Pressurant Bottle Recharge

Recharge Process Flow Rate Trade - The LN2 recharge bottle process has been analyzed to determine the minimum flow rate to fill the bottle, from an initial wall temperature of 300 K (540 R), that will result in the required charge mass of 5.9 kg (13 lbm). The initial temperature of 300 K (540 R) was used to ensure margin on the given flow rate. Again, MMCAP was used to model the no-vent fill process. The flow into the bottle was modeled as a pressure driven flow. That is, the flow rate into the bottle was dependent on the pressure difference between the bottle and the inlet. Once the tank pressure had risen to the inlet value 172 kPa (25 psia), the flow would cease. Therefore, it was very easy to determine the total fluid mass transferred into the tank. Parametric runs were made with different flow rates, at a pressure drop of 68.9 kPa (10 psid), which actually corresponds to different line impedances. The results illustrated in Figure 4.7.3-1 show that the desired charge amount can be obtained if the flow rate is 681 kg/hr (1500 lbm/hr) or greater. This value was then chosen as the flow rate for the first bottle recharge.

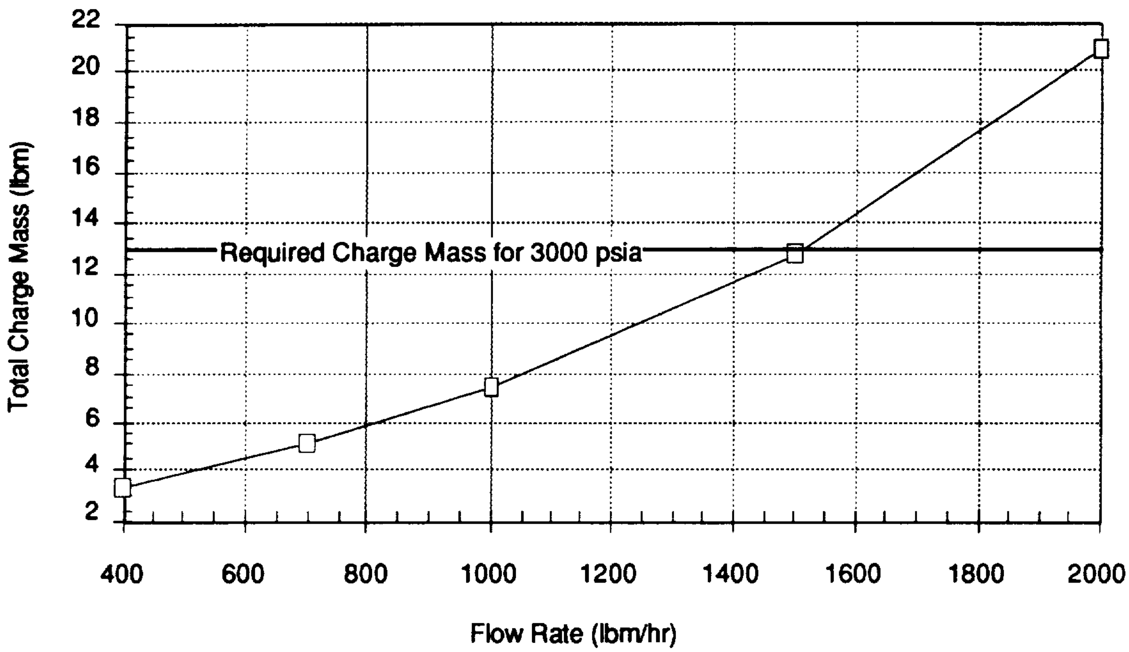


Figure 4.7.3-1 Pressurant Bottle Recharge Flow Rate Selection

Pressurant Bottle Thermal Coating Trade - The warm-up portion of the pressurant bottle recharge has been analyzed to determine the required time to reach steady-state, and to evaluate possible tank surface coatings. The analysis used the program MMCAP since it has the capability to model the entire fluid dynamics of this process, and the external heat load onto the tank. The primary driver of the warm-up time is the thermal environment of the Orbiter. Without a specific manifest a detailed thermal model cannot be generated. A typical average value of 269 K (484 R) has been recommended for this study, so this value was used. This value is to be used as a full coverage radiation source (i.e. the view factors are assumed to be 1). Therefore the exterior heat transfer can be predicted as a simple radiation conductor. The tank warm-up was modeled with two different tank emissivities. The first is 0.25 and corresponds to a bare titanium tank. Another case was run with an emissivity of 0.85 which corresponds to white paint. The plot in Figure 4.7.3-2 presents the predicted pressures for both cases analyzed. As assumed, the high emissivity bottle warmed up very quickly. The low emissivity bottle also reached steady state in about 48 hours. Due to this analysis the time allocated to tank warm-up has been set to 1 day. The white paint is the option chosen since this allows for the faster warm-up and allows for lower tank temperature swings.

The plot in Figure 4.7.3-2 shows the pressure to exceed the 3000 psia limit set for the bottle. This result is due to the fact that the run was begun with 13 lbm of liquid in the tank. The ullage mass (~0.4 lbm) was not accounted for. The actual requirement is to have ~13 lbm of nitrogen (gas or liquid) in the tank at the end of the no-vent fill. This fact must accounted for in the timing of the recharge.

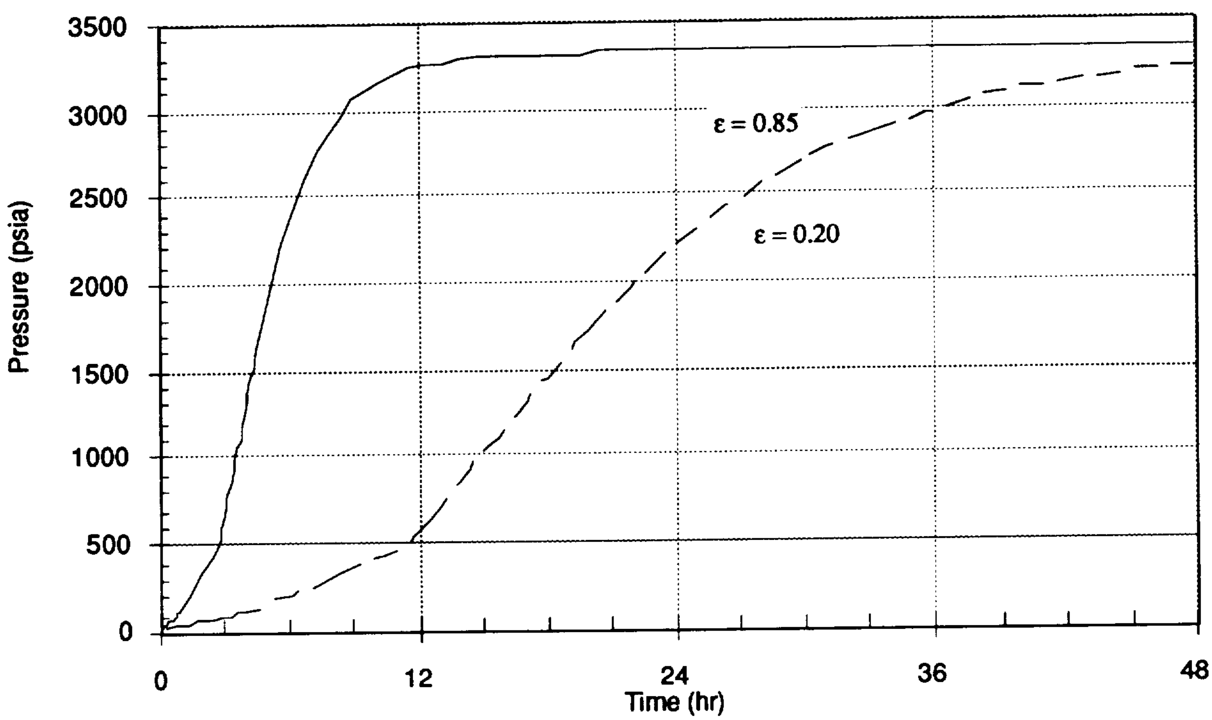


Figure 4.7.3-2 Pressurant Bottle Surface Coating Sensitivity

<u>Pressurant Bottle Chilldown Trade</u> - Figure 4.7.3-3 illustrates two pressurant bottle chilldown approaches and Table 4.7.3-1 summarizes the analysis to determine the preferred chilldown method to be used in the pressurant bottle recharge. To generate the data two MMCAP models were developed that model the chilldown of the pressurant bottle to a target temperature of 194 K (350 R). The program MMCAP was used in this analysis since it can simultaneously model the wall to liquid heat transfer, the interfacial heat transfer, and the thermodynamics during the vent.

The first case modeled was a single charge-hold-vent cycle. One limiting assumption was made in the process in that the hold period will only be long enough to completely boil the charge fluid, i.e. we will not attempt to chill the tank via sensible heating of the fluid. This decision was made to allow for a quick chilldown, and to avoid any uncertainty over the true amount of low-g convective heat transfer. Several runs were made until the correct chilldown charge could be found. It turned out to be ~1.5 kg

(~3.2 lbm), which corresponds to a 12 second inflow at approximately 455 kg/hr (1000 lbm/hr). The maximum pressure in the tank was 1930 kPa (280 psia), which demonstrates one advantage this chilldown method has with respect to high pressure bottles. Since the allowed pressure is very high, the chilldown can be performed in much less time since a larger charge mass can be used (than for a propellant tank).

The flow-through concept was developed to allow for easy chilling of the bottle from an operational point of view. The idea is to utilize fluid that would simply be thrown away, to chill the pressurant bottle down. There is no specific sequencing of major hardware impacts as there would be for the charge-hold-vent or external heat exchanger methods. The flow-through chilldown required 2.5 minutes at a flow rate of 455 kg/hr (1000 lbm/hr). This results in a fluid consumption amount of 19.1 kg (42.0 lbm), which is very inefficient. The slightly lower chilldown time is not great enough to off set the greater fluid consumption amount. From all of the analysis the charge-hold-vent option was chosen to the the preferred option.

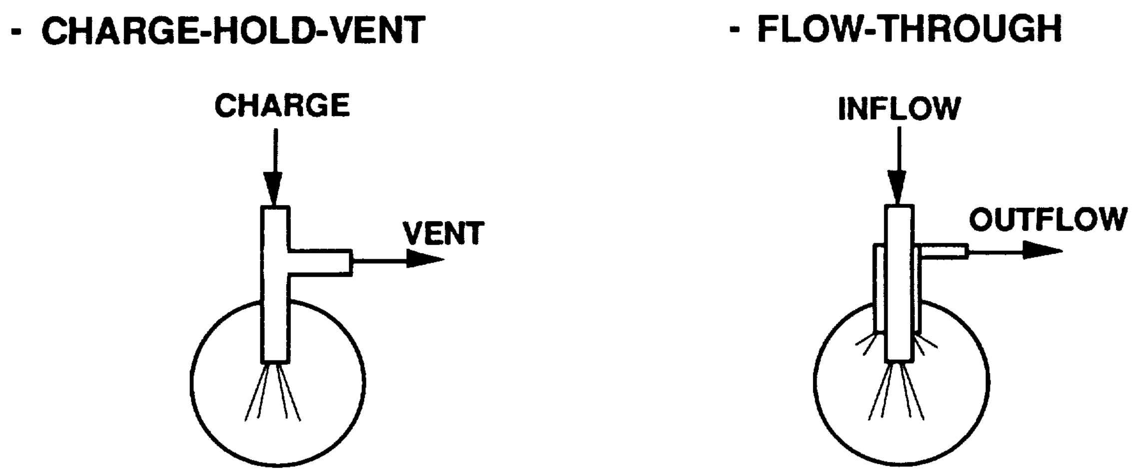


Figure 4.7.3-3 Pressurant Bottle Chilldown Options

Table 4.7.3-1 Chilldown Options Trade Study

CHILLDOWN	TARGET TEMPERATURE (R)	TIME (MINUTES)	LN2 USED (LBM)
FLOW-THROUGH	350	3.5	42.0
CHARGE-HOLD-VENT	350	5.0	3.5

There are hardware concerns that make the charge-hold-vent concept desirable too. As is shown on the chart, the bottle can have a single inlet with a valve at the tee. This design is easier than that required for the other chilldown concept. The flow through option requires that the inlet must be concentric since there is only one 1.27 cm (1/2 inch) boss in the chosen pressurant bottle. The manner in which this design would be achieved is shown on the chart, where the inlet will be the center tube, and the annulus will be the vent.

4.7.4 Active Pressure Control

Tank Size & Heating rate Selection - The CONE storage tank size was determined by Rayleigh number scaling to the STV core tanks in LEO with stratification time as a constraint. The Rayleigh number scaling relationships are illustrated in Figure 4.7.4-1, which shows the ratio of model to prototype heat fluxes as functions of model tank size. The STV H_2 and O_2 core tanks are the prototype tanks and two curves are presented for each prototype tank corresponding to the expected range of prototype to model acceleration ratios. The curves overlap in the central portion of the figure. Under those conditions, the CONE tank could simultaneously model the STV core H_2 and O_2 tanks, although not at the same acceleration ratio. The overlapping region indicates a desirable region of tank sizes and heat fluxes.

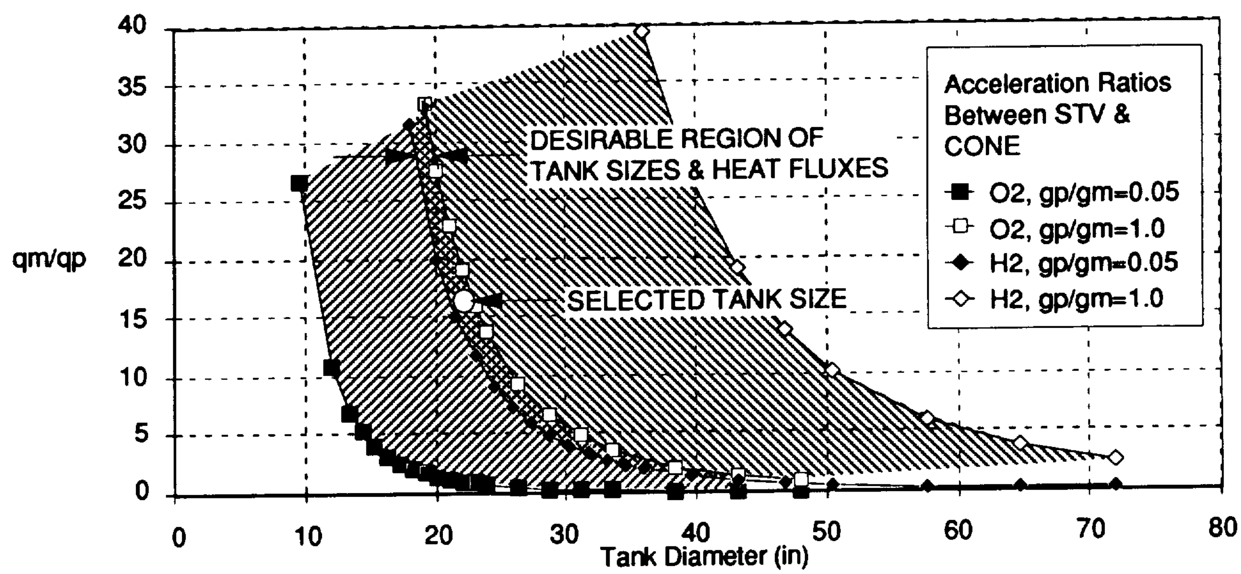


Figure 4.7.4-1 Tank Size and Heating Rate Selection

This region was examined in more detail to determine the maximum tank size which would permit a pressure rise experiment in 1 shift. This was analyzed with the homogeneous model to determine the amount of time required to produce a 34.5 kPa (5 psi) pressure rise at the 80% fill level in a tank with the proper aspect ratio. The actual pressure rise will probably be larger due to thermal stratification, but 34.5 kPa (5 psi) in a mixed condition is required to provide adequate initial conditions for the CHX pressure reduction experiments. Each pressure rise experiment will be followed by 1 mixing and two pressure reduction tests. The results are presented in Figure 4.7.4-2 which shows time as a function of tank size. The maximum tank size is slightly over 61 cm (24 inches). An examination of existing tanks revealed a tank manufactured by TRW PSI (P/N 80310-1) that was slightly smaller than the maximum. This tank could be used with some modification and was selected as the storage tank pressure vessel.

Fluid Stratification Thermodynamic Analysis - The CONE storage tank will be locked-up to provide the pressure rise required to precede the active pressure control (APC) and mixing tests to be conducted in the experiment set. Fluid stratification predictions have been made using the STRAT computer program to insure that the maximum possible pressure rise will not exceed tank allowables of 345 kPa (50 psia).

It has been determined from our homogeneous pressure rise model that for a nearly full tank (80%) it requires about 5 hours of heating to establish a 34.5 kPa (5 psid) pressure rise in the tank (mixed condition). Similarly, for a reduced fill level (40%), about 2.7 hours is required for the tank contents to become overpressurized by 34.5 kPa (5 psid) in a homogeneous condition. The tank heat flux contributing to the tank's thermal input was defined to be 22.7 w/m^2 (7.2 Btu/hr-ft^2) for both tests. Actual tank fluid stratification pressure rises will be higher due to the nature of the distributed temperatures in the fluid resulting from the net effects of buoyant flow due to wall heating of the storage tank.

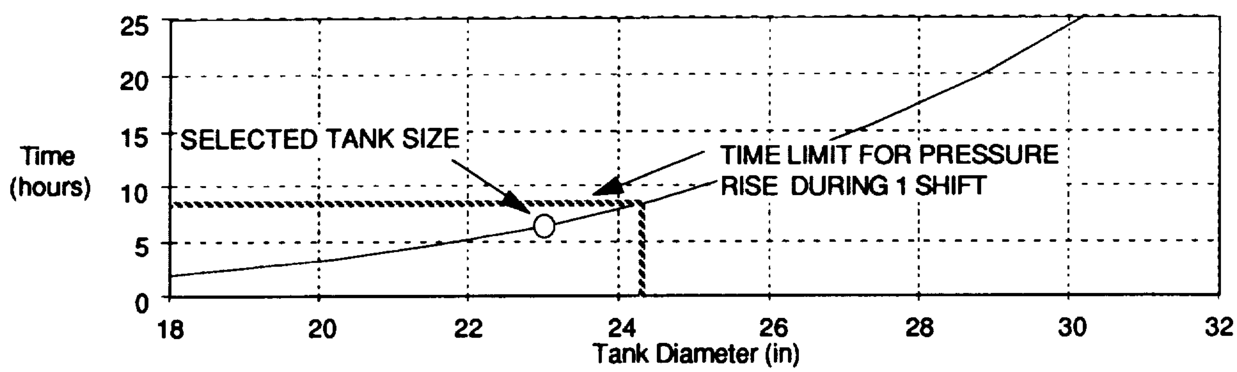


Figure 4.7.4-2 Tank Size vs Pressure Rise Limitation

The results shown in Figure 4.7.4-3 illustrate the results of STRAT modeling two of the stratification tests in the CONE experiment. These two tests correspond to PRD Test numbers 5.2 and 5.4 in the experiment matrix. Stratification Test PRD 5.2 is an initially settled, high fill level (80%) test at the background acceleration of 2.E-6 g's and with no wall-to-ullage contact area. Stratification Test PRD 5.4 is an initially settled, low fill level test (40%) also being conducted at the orbiter background acceleration level as well, but this model assumes a 10% tank wall areal contact with the ullage bubble space. In both of these tests, the ullage will probably have minimal contact with the wall due to the low background acceleration levels experienced during the mission.

Figure 4.7.4-3 shows the actual pressure rises predicted from the fluid stratification model and how each of these higher pressure rise rates relates to the homogeneous (mixed) pressure rise rates. The homogeneous pressures are those that would result if the tank contents were well mixed for all points in time during the test operation. This resulted in the desired 34 kPa (5 psia) pressure increase occurring in 2.7 hours. The maximum pressure rise due to stratification occurs at the lower fill level and results in an approximate 216 kPa (31.3 psia) pressure at 2.7 hours. At the high fill level, only 181 kPa (26.3 psia) total pressure is realized since there exists more liquid with which to absorb the influx of heat.

Mixer Pump Flow Rate Selection Trade - Figure 4.7.4-4 describes the development of the requirements for the two mixer flow rates to be used in the active pressure control testing. The tank design had generated the requirement for a 1.27 cm (1/2 inch) mixing nozzle so that size jet was used in all of the analyses. The correlation for interface stability during mixing (Reference 4.7-1) was used to determine the required mixer flow rates. The plot shows the interface stability number Fc at various flow rates and fill levels. LeRC direction had specified that the low fill level should have a flow rate low enough to maintain flow regime I (a stable interface) and that flow regime IV (a fully shattered interface with liquid flowing down the walls) should be obtained a the high fill level. These two flow regimes correspond to Fc numbers of 0.4 and 2.5 to 3.0 respectively, and the two lines are also shown on the chart. The two points that are highlighted show the intercept points of the curves. The points intercept at the flow rates of 50 and 150 kg/hr (110 and 330 lbm/hr), therefore these two values were chosen.

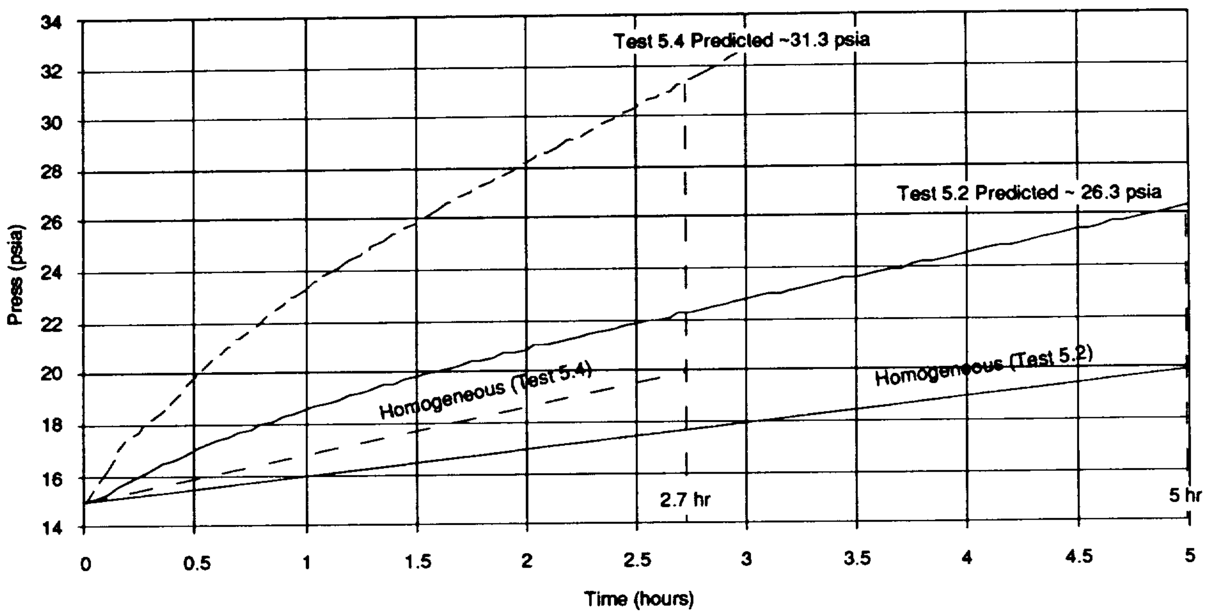


Figure 4.7.4-3 Stratified Pressure Rise Predictions

The dimensionless performance of the mixer pump is presented in Figure 4.7.4-5. Illustrated is the head coefficient, Y, as a function of the flow coefficient, Q. The relationship is empirical in nature but is also influenced by the impeller design. These relationships are used to generate head/flow curves given impeller rotation rate and the diameter of the throat and impeller.

Dimensional pump performance is illustrated in Figure 4.7.4-6. Shown are the pressure rise across pump as a function of pump flow rate with pump speed as a parameter. The curves were generated with the head/flow coefficient relationship presented in the previous figure. The variation in pump speeds is required to meet the flow rate variation of 50-150 kg/hr (110-330 lbm/hr) as required for the active pressure control experiments.

An assessment of the prototype mixer pump power is shown in Table 4.7.4-1. The table contains the hydraulic power, losses, and the total power which is the sum of the previous 2 entries. The table also contains an evaluation of pump power as a percentage of total tank heating. The total pump power as a percentage of total tank heating is insignificant at the low flow rate but it becomes appreciable at the higher flow rate. This was expected because the pump was designed for simplicity and low cost, not for efficiency. If efficiency becomes a driver for the flight program, then the pump design could be modified to improve efficiency.

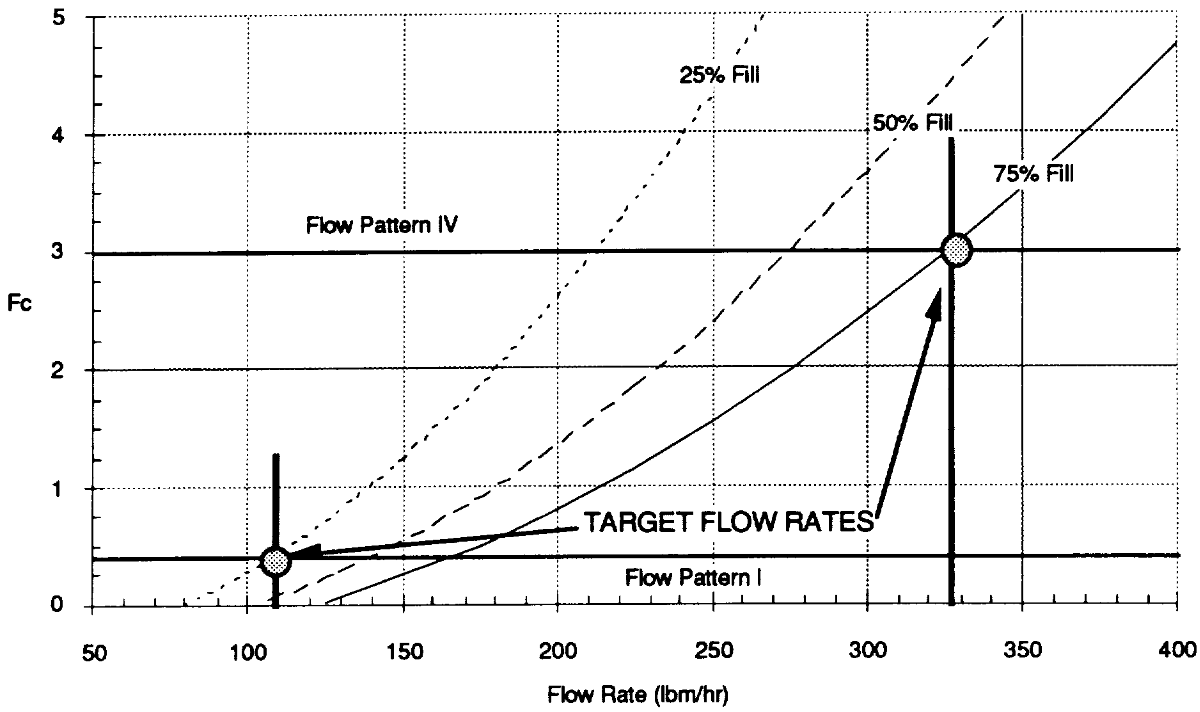


Figure 4.7.4-4 Mixer Pump Flow Rate Selection Trade

$$\Delta P = \frac{\Psi V_{tip} \rho}{g} \qquad \Phi = \frac{V_{throat}}{V_{tip}}$$

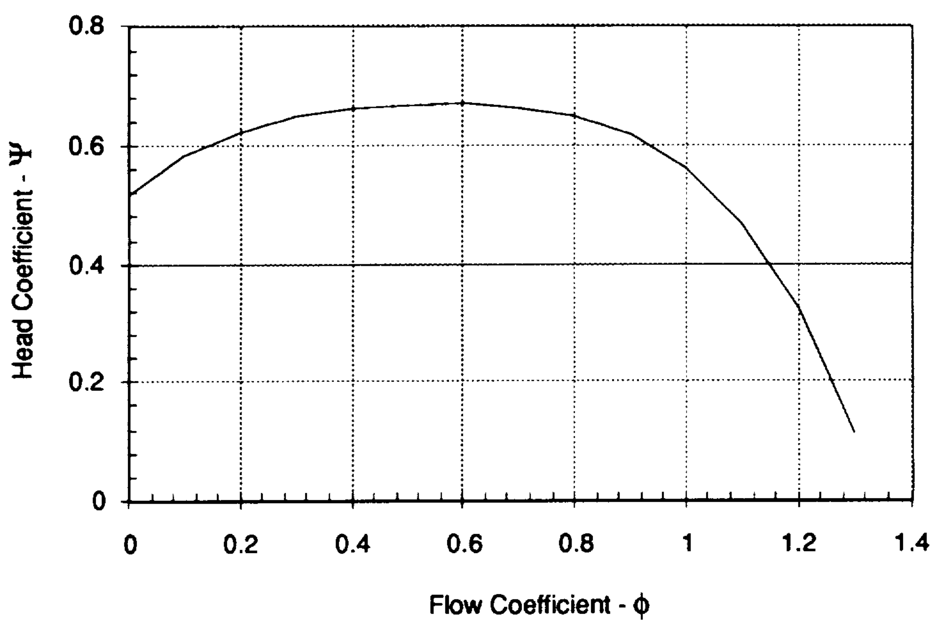


Figure 4.7.4-5 Mixer Pump Head and Flow Coefficients

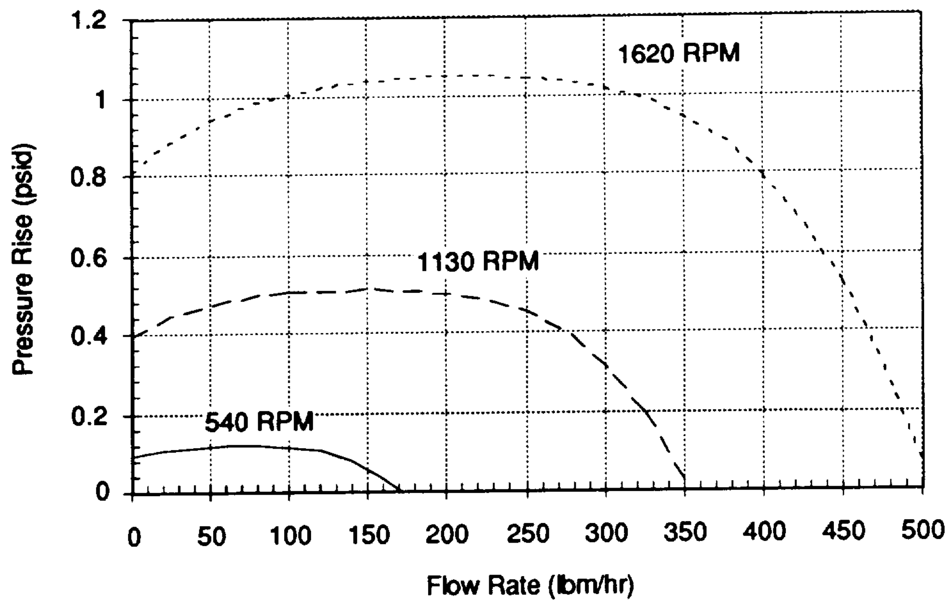


Figure 4.7.4-6 Mixer Pump Performance

Table 4.7.4-1 Pump Efficiency Assessment

	100 lbm/hr		300 lbm/hr	
	Power (W)	% of Total	Power (W)	% of Total
Pump Power	0.0122	0.46	0.33	11.12
Losses	0.1517	5.44	0.877	24.95
Total Power	0.1639	5.85	1.207	31.39

CHX Flow Rate Selection - CHX flow rates were determined by considering the amount of time required to reduce tank pressure 17.2 kPa (2.5 psi) at two fill levels and heating rates as defined by the active pressure control experiment. The analysis was performed with the homogeneous model and the results are presented in the accompanying figure. At the lowest heating rate and fill level, the pressure reduction time was limited by the amount of time to mix the tank contents. It would be inefficient to attempt a pressure reduction in a shorter interval than would be required to mix the tank. The high CHX flow rate was chosen as 2.3 kg/hr (5.0 lbm/hr) to prevent a too rapid pressure decay in the low fill level and heating rate test. The lower flow rate was selected so that a single J-T expander could be used for both flow rates. This resulted in an increase from the PRR flow rate of 1.4 to 1.8 kg/hr (3.0 lbm/hr to 4.0 lbm/hr). Limiting the range of CHX flow rates does not diminish the return on the experiment because the flow variation will result in significantly different conditions in the CHX, so there will be an opportunity to assess the effect different flow rates have on CHX performance. Figure 4.7.4-7 illustrates the pressure reduction time as a function of flow rate for the 4 pressure reduction cases.

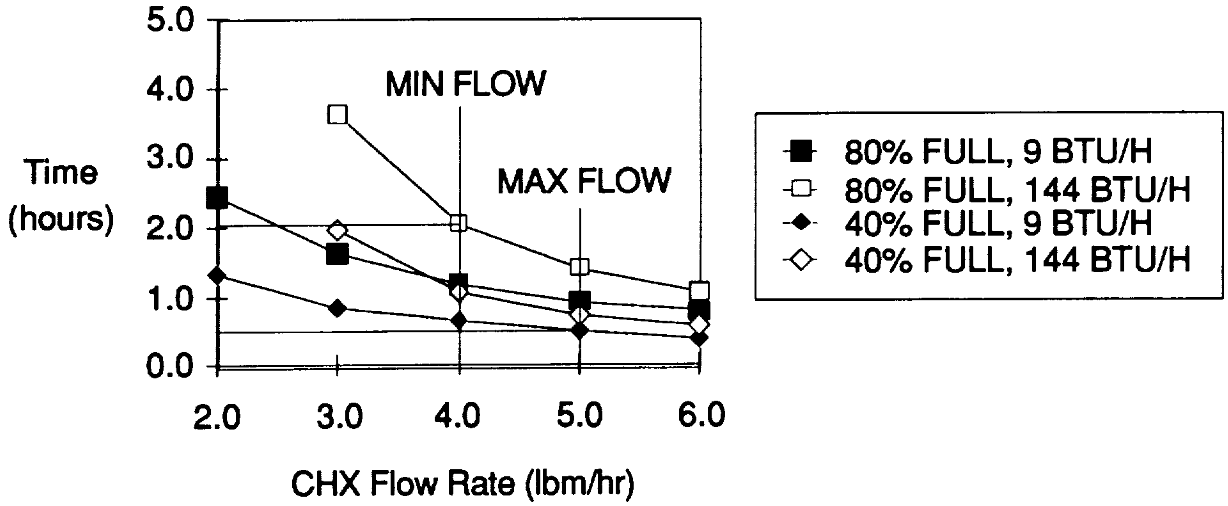


Figure 4.7.4-7 Pressure Reduction Time Sensitivity

CHX Sizing Analysis - These charts summarize the analysis of the Compact Heat Exchanger (CHX). The design had to meet a varying set of flow rates with the requirement that the flow should have a minimal pressure drop while having a high amount of efficiency with respect to the heat transfer. Table 4.7.4-2 presents the full set of flow rates that the CHX will encounter in usage, therefore the set of parameters to use in the analysis.

The results of the CHX analysis are presented Table 4.7.4-3. The CHX size that was found to work best is a 1.59 cm (5/8 inch) outer tube, a 0.95 cm (3/8 inch) inner tube, and a 0.07 cm (0.028 inch) wall thickness for both tubes. This CHX size resulted in a design length of 4.11 m (13.5 feet) which has been set to provide very little margin on the worst case analyzed, which was the case of low flow on both sides of the CHX. This condition resulted in the longest length for burnout due to the fact that

Table 4.7.4-2 Pressure Reduction Cases

Case	Flow Cold (lbm/hr)	Flow Hot (lbm/hr)	P Cold (psia)	P Hot (psia)
1	4	110	8.7	15
2	4	330	8.7	15
3	5	110	4.0	15
4	5	330	4.0	15

the warm side has a low velocity and therefore a low heat transfer coefficient while the cold side was throttled to only 60.0 kPa (8.7 psia), resulting in a lower temperature difference for heat transfer. By designing the line for little margin in the worst case will allow for a good test of the design approach. If the flow does completely boil by the exit, the approach will be shown to be conservative. If it does not, the testing will not be hampered due to the very low burnout lengths that occur for the other cases. Therefore the CHX design can be stressed in one test while maintaining a good margin in the others. The table presents the results of all the analyses including an extrapolation of the pressure drops from a line of the length to burnout. The CHX has a length of 4.11 m (13.5 ft) and accommodates all cases.

Table 4.7.4-3 CHX Sizing Analysis Results

Case	Length (ft)	Q (BTU)	ΔT Hot (R)	ΔP Hot (psia)	ΔP Cold (psia)	ΔP Hot (longest L) (psia)	ΔP Cold (longest L) (psia)
1	13.1	335.9	6.20	0.043	0.255	0.043	0.255
2	4.3	335.4	2.06	0.109	0.075	0.331	0.376
3	4.6	410.9	7.59	0.015	0.237	0.043	1.082
4	2.0	419.9	2.58	0.051	0.096	0.331	1.026

Homogeneous Pressure Reduction Simulation - The simulation results of the active pressure control experiments are shown in Table 4.7.4-4. The simulations were performed with the integral homogeneous model. The test number column refers to the test number used in the PRD. The fill level, CHX rate, and the heat rate are the conditions for each experiment. The time and consumed fluid to decrease the tank pressure are summarized in the right two columns. The analysis did not provide any information about the conditions in the tank during the pressure reduction experiments, but it can be assumed that the pressure response is approximately linear.

Table 4.7.4-4 Pressure Reduction Results

TEST #	FILL LEVEL (%)	CHX RATE (LBM/HR)	HEAT RATE (BTU/HR)	Δ TIME (HR)	Δ MASS (LBM)
9	80	4	9	1.19	4.74
10	80	4	144	2.04	8.16
11	80	5	9	0.94	4.72
12	80	5	144	1.41	7.07
13	40	4	9	0.64	2.55
14	40	4	144	1.09	4.38
15	40	5	9	0.51	2.53
16	40	5	144	0.76	3.80

Non-Homogeneous Pressure Reduction Simulation - Integrated active pressure control modeling was performed with a modified version of computer program MMCAP. The model, which is illustrated in Figure 4.7.4-8, consisted of two liquid nodes, one vapor node, and two heat exchangers to simulate the two sides of the compact heat exchanger. The modifications to MMCAP included a mixer model and a special flow area input to account for the annular flow in the CHX. The simulation was performed to obtain pressure and thermal gradient histories during the mixing and pressure reduction experiments. The analysis was also performed to obtain temperature and heat transfer profiles in the CHX. This information was useful in verifying the original CHX sizing analysis which was performed with another model.

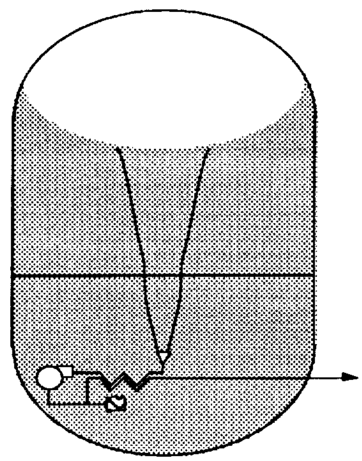


Figure 4.7.4-8 Integrated Active Pressure Control Model

The results of an active pressure control simulation are shown in Figure 4.7.4-9. The simulation conditions were for an 80% full case, a mixer flow rate of 50 kg/hr (110 lb/hr), a CHX flow rate of 2.3 kg/hr (5 lb/hr) and an initial tank heating rate of 2.64 w (9 BTU/hr) which is then increased to 42.2 w (144 BTU/hr). One mixing and two pressure reduction experiments are illustrated. The initial conditions assumed that the liquid was stratified into two equal volume portions with sufficient temperature difference so that the tank pressure would stabilize at 20 psi following mixing. The mixing experiment occurred during the first 15 minutes of the simulation and ended with the activation of the CHX, which began the pressure reduction reduction experiment. The second pressure reduction experiment began with the increase in tank heating. The mixing experiment indicated an initial rapid decrease in tank pressure followed by a leveling off of the pressure decay as the tank contents became mixed. Activating the CHX resulted in an increased pressure decay which remained nearly constant until the tank heating was increased. The change in tank heating resulted in an abrupt change in the pressure decay rate. These results are consistent with the active pressure control modeling performed with a homogeneous model as would be expected because homogeneous conditions prevailed in the tank following mixing.

The temperature distribution in the CHX is illustrated in Figure 4.7.4-10. The single phase side has an additional segment at the inlet to account for the single phase flow through the mixer pump. The heat transfer from the pump causes a slight increase in single phase fluid temperature before the recirculating fluid is cooled by the two-phase fluid. The single-phase fluid experiences a rapid decrease in temperature as it is cooled. The cooling rate decreases, however, after the two-phase fluid is completely vaporized. Dryout occurs between 1.2 to 1.7 m (4 and 5.5 feet). Following dryout, the temperatures of the liquid and gas sides converge to a common value. These results are consistent with the CHX sizi:.g analysis which predicted a two-phase dryout length of 1.4 m (4.6 ft).

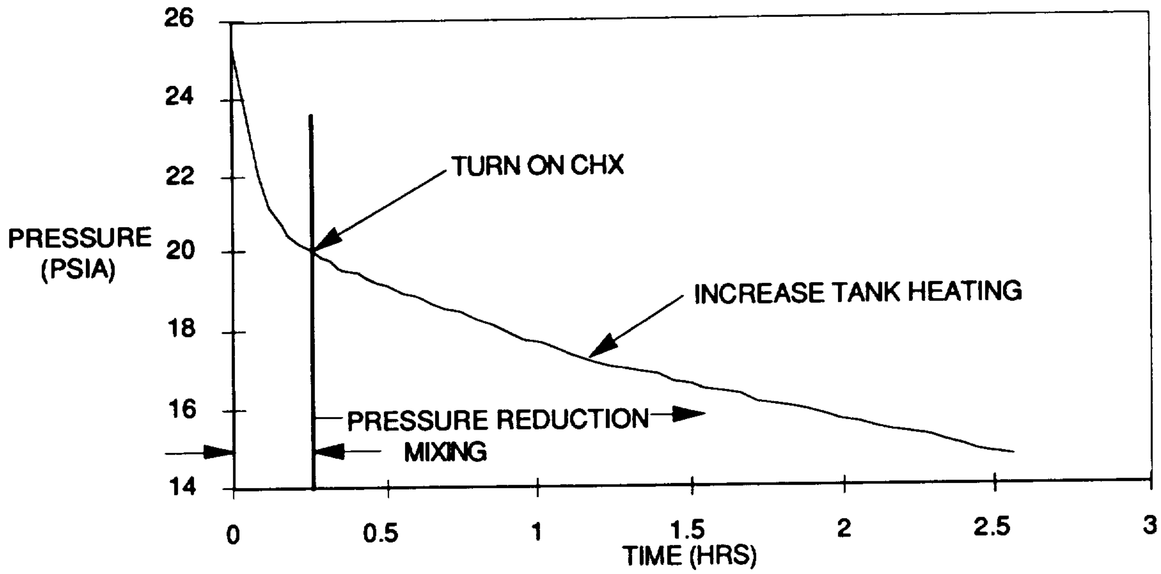


Figure 4.7.4-9 Integrated Active Pressure Control Simulation Results

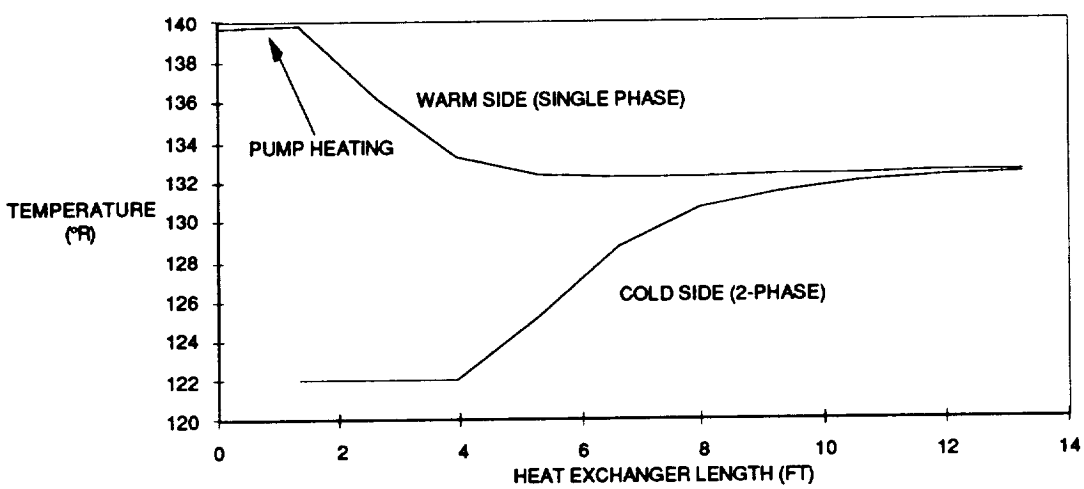


Figure 4.7.4-10 CHX Conditions

4.7.5 LAD Performance

Storage Tank Orientation Trade - A trade study was performed to determine the best orientation for the storage tank. Two orientations were considered; tank long axis parallel to the orbiter x-axis or parallel to the orbiter z-axis. The orientations were compared for the following issues:

Liquid/Vapor Interface Stability - The z-axis orientation is preferable because a stable liquid interface is possible in a high drag orbiter attitude. The interface stability results from the geometry of the tank and not from dominant body forces. Orienting the tank along the high drag axis provides the maximum settling force which should minimize fluid disturbances when the orbiter is in a high drag attitude.

PRCS Settling in Stable I/F Direction - PRCS is available in either orientation, but a higher acceleration is available in the z-axis orientation. Therefore, the z-axis orientation is preferred in terms of PRCS settling.

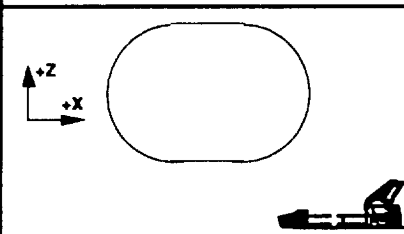
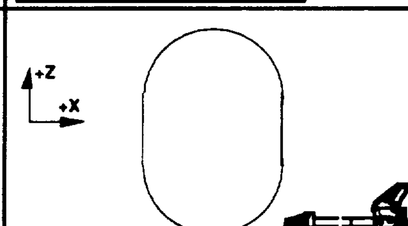
VRCS Settling in Stable I/F Direction - This settling is available only in the z-axis orientation. This is a significant discriminator between the two tank orientations.

OMS Settling in Stable I/F Direction - This settling is available only in the x-orientation. The x-axis orientation would be preferred if such an operation was required. Currently, OMS settling is not required, so this is an insignificant discriminator.

Isolation of LAD from Ullage During Ascent - The x-axis orientation would have truncated channels to prevent LAD breakdown during ascent. The ullage could remain submerged in the z-axis orientation by rotating the LAD so that no channel penetrates the ullage during launch. Such an approach was used in the Intelsat V tank. The z-axis is preferred for LAD isolation.

Based on these results, the z-axis orientation was chosen for CONE. Table 4.7.5-1 documents the trade.

Table 4.7.5-1 Storage Tank Orientation Trade

ISSUE	X AXIS ORIENTATION	Z AXIS ORIENTATION
ORIENTATION		
LIQUID/VAPOR INTERFACE STABILITY	STABLE INTERFACE IN LOW DRAG MODE, (BO=0.29)	STABLE INTERFACE IN HIGH DRAG MODE (BO=0.15)
PRCS SETTLING IN STABLE I/F DIRECTION	0.013G'S	0.024 G'S
VRCS SETTLING IN STABLE I/F DIRECTION	NOT AVAILABLE	0.003 G'S
OMS SETTLING IN STABLE I/F DIRECTION	0.06 G'S	NOT AVAILABLE
ISOLATION OF LAD FROM ULLAGE DURING ASCENT	TRUNCATED CHANNELS	ORIENT LAD

LAD Configuration Trade - A trade study was performed, as shown in Figure 4.7.5-1, to determine the best configuration for the LAD. Two configurations were considered; symmetric 4 channel and 3 channel configurations. The LAD configuration trade assumed that the tank is oriented parallel with the orbiter z-axis. One of the discriminators was maximum ullage volume. The 4 channel configuration permits a maximum 7% ullage whereas the 3 channel configuration permits a 17% ullage. This is particularly important because the vent placement permits a minimum 5% ullage. The 4 channel configuration would permit only 2% boiloff before the tank would have to be topped off. The 3 channel configuration, however, could accommodate 10% boiloff before replenishing. Thus, the 3 channel configuration would permit 5 times the ground hold interval as the 4 channel device. Liquid consumption is not a critical issue in CONE, so the storage tank could be flown with the larger initial ullage volume without degrading experiment return. Another consideration is the position of the channels. In the 4 channel configuration, it is possible that x-axis acceleration could settle liquid away from any channel. In the 3 channel configuration, however, x-axis acceleration would settle liquid over one channel, thereby permitting continued liquid expulsion. Based on these results, the 3 channel configuration was chosen for CONE.

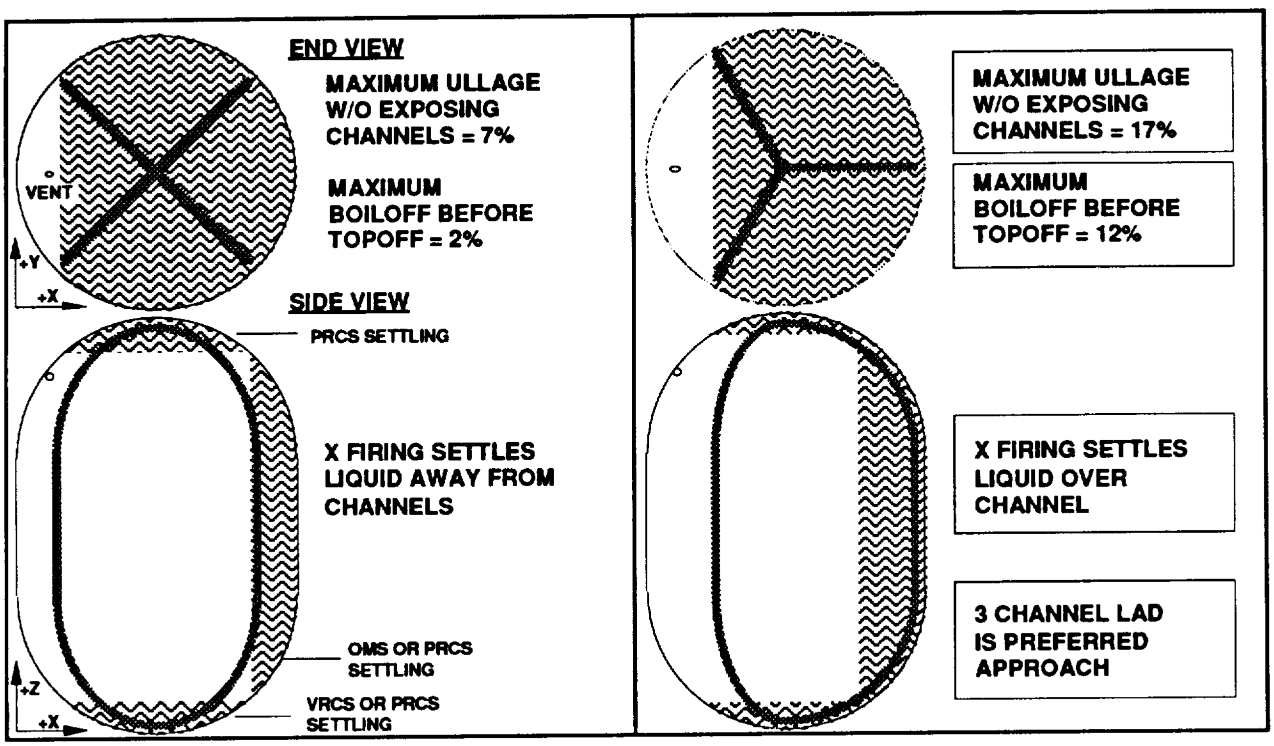


Figure 4.7.5-1 LAD Configuration Trade

An analysis was performed to assess the sensitivities of liquid outflow rate and acceleration environment for liquid expulsion efficiency of the CONE 325x2300 fine mesh screen capillary liquid acquisition device. The analysis was performed for purposes of determining the sensitivity that different flow rate conditions have on the overall breakdown expulsion efficiency of the CONE storage tank. The analysis was important because the customer directed the Liquid Acquisition Device Performance Expulsion Efficiency Experiment to become a demonstration. It became a demonstration from the last phase of the program when it was desired to examine best possible expulsion performance at a lower outflow rate, typical of a full-scale application, and without any thruster requirements (background acceleration).

The LAD stressing with thrusting accelerations was eliminated from that specified in earlier phases of the CONE program. A 45 kg/hr (100 lbm/hr) outflow rate is used for the first outflow test and to avoid using the same flow rate in the expulsion efficiency test, a slightly higher outflow rate of 227 kg/hr (500 lbm/hr) will be used in order to obtain variation in flow rate for the tests.

Figure 4.7.5-2 shows the effective breakdown point for a series of assumed LAD channel flow conditions. Breakdown occurs when only LAD residuals remain. The analysis was bounded by 45 and 227 kg/hr (100 and 500 lbm/hr) flow rates while considering different flow conditions through the legs of the 3-channel CONE LAD design. The extreme case is the full flow rate of 227 kg (500 lbm/hr) through a single channel of the LAD, whereas the minimum flow case is dictated by allowing the 45 kg/hr (100 lbm/hr) flow rate to be split equally between all three legs of the device. Even though the 227 kg/hr (500 lbm/hr) flow through a single leg only very slightly reduces the breakdown point which is not even noticeable, the more likely flow situation for 227 kg/hr (500 lbm/hr) outflow would be about 76 kg/hr (167 lbm/hr) per leg which shows no difference in the breakdown point. The primary pressure losses in the LAD for the liquid expulsion test is by screen flow loss since the acceleration is low and the flow rates are low. Therefore, since no considerable differences in LAD performance exist between the 45 and 227 kg/hr (100 and 500 lbm/hr) outflow rates, the flow rate of 227 kg/hr (500 lbm/hr) was selected to conduct the expulsion efficiency demonstration.

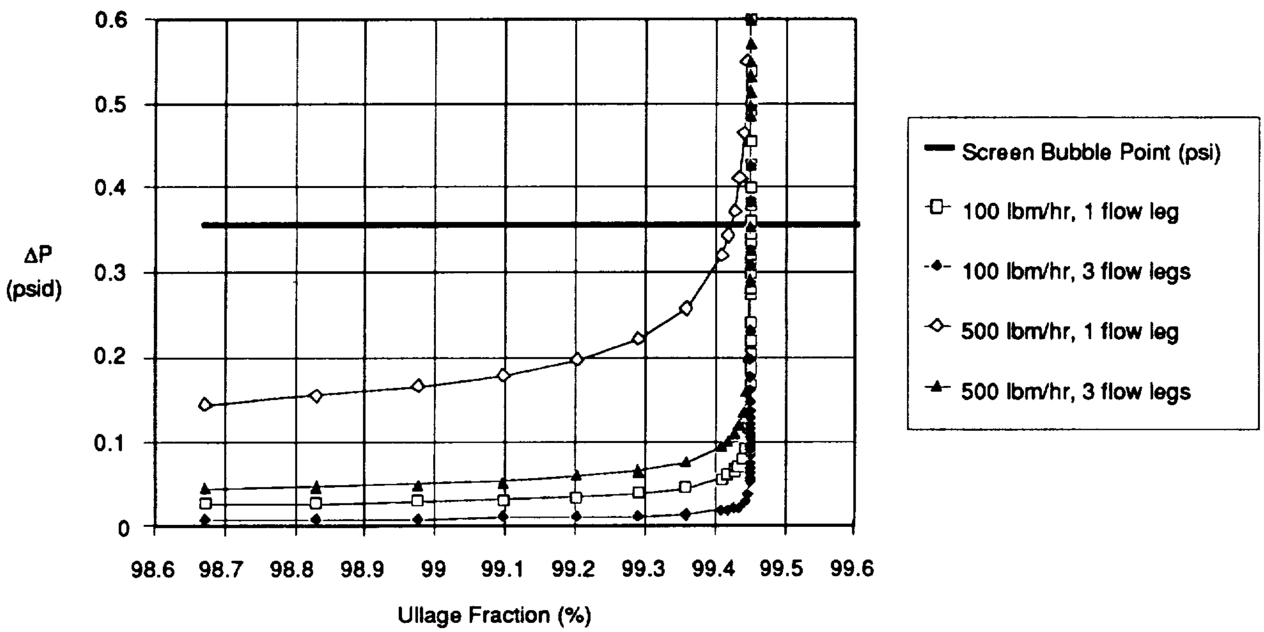


Figure 4.7.5-2 LAD Expulsion Efficiency Analysis

A computer spreadsheet model was developed and used to calculate the individual pressure drop components for the pressure drop expected in the CONE LAD for a nearly empty tank while outflowing at 227 kg/hr (500 lbm/hr). Since the pressure head alone will not break down the LAD in the CONE tank, at some point during the liquid flow in the LAD, the screen is expected to break down by frictional flow losses across a reduced screen area while sustaining a constant outflow rate. A higher flow rate has a more pronounced effect on screen breakdown as opposed to the substantially reduced pressure head and low channel flow losses. Shown in Figure 4.7.5-3 is the case of 227 kg/hr (500 lbm/hr) flow through a single channel. The magnitudes of the pressure loss components for our 325x2300 fine mesh screen LAD in the CONE storage tank at the time the tank is about 99% empty and the acceleration is the background level. Note that the ΔP scale is a log scale for clarity of the great differences in the magnitudes of the pressure drop components. Head losses are essentially negligible and channel flow losses account for about 3% of the total pressure drop at breakdown. Therefore, about 97% of the pressure drop occurs as screen loss. Screen breakdown will occur near the end of the tank expulsion when less and less screen area is submerged in the liquid. At the end of the tank expulsion, the flow area of the screen is so reduced that the flow velocity across the screen increases to the point that pressure losses become substantial, even with low flow rates. With low flow rates however, the point of breakdown becomes less and less discernable and essentially approaches the LAD residuals in the tank. Unless the flow rate is extremely high > 681 kg/hr (1,500 lbm/hr), breakdown will occur very near maximum expulsion efficiency of the tank where the area of the submerged screen becomes nearly zero and all of the contents in the tank have been expelled except for the quantity of fluid in the LAD itself.

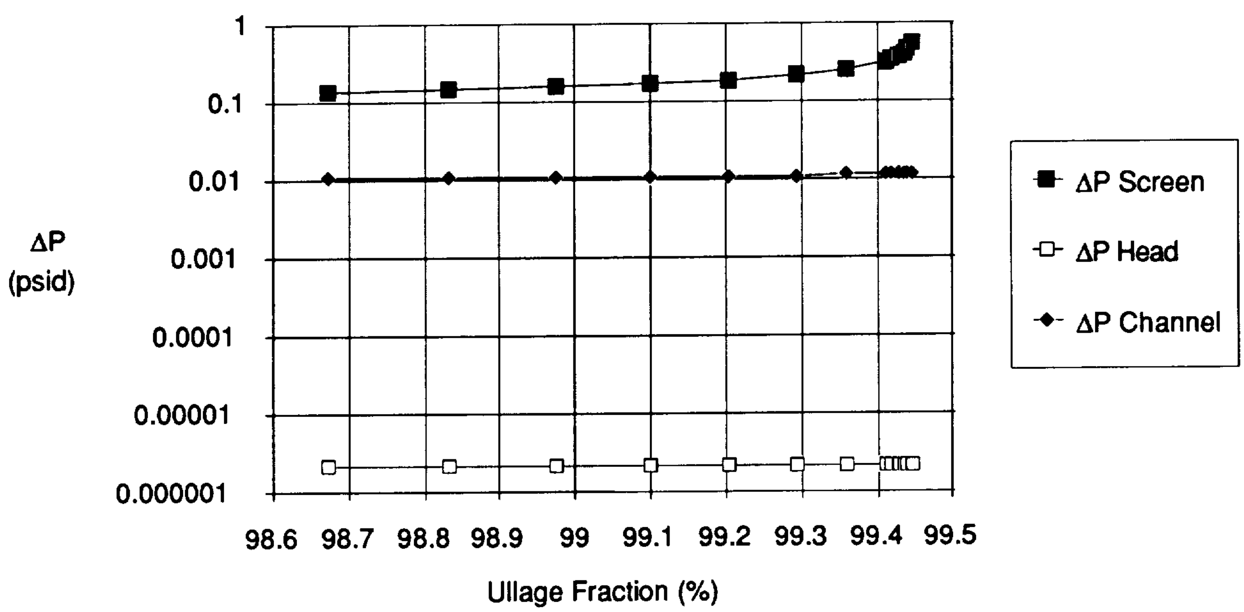


Figure 4.7.5-3 LAD Pressure Drop Components

4.7.6 Experiment Subsystem Control

Experiment Subsystem Control Networks - Control algorithms have been defined to perform automatic control of critical events many of which are safety related. Most pressure relief valves are complemented with venting pressure using system valving before manual relief valve and/or burst disc settings are exceeded. Approximately half of the defined control networks are associated with safety, while the rest perform various component limit cycling. As other requirements are defined, the use of these algorithms will be expanded. For the most part, these functions will reside in software and will be continuously active to perform required actions should they be required. Table 4.7.6-1 lists the control networks presently defined for CONE.

<u>Passive Pressure Control</u> - The liquid storage demonstrations require controlling tank pressure with a passive pressure control heat exchanger. The demonstration will be performed by turning off the heat exchanger and waiting until the tank pressure increases 0.69 kPa (0.1 psi). The heat exchanger will then be turned on until the pressure decays 0.69 kPa (0.1 psi). The narrow control band was necessitated by the limited amount of time available to perform the demonstration and the desire to achieve multiple cycles to demonstrate pressure control. The narrow control band appears to be in conflict with the 0.69 kPa (0.1 psi) accuracy of the pressure transducer. There should be no problem with the current system, however, because relative accuracy is required, not absolute accuracy. It is not necessary to know the actual tank pressure, only the pressure relative to the last time the pressure control function was activated. The measurement system uses an 8 bit word for the 69 kPa (10 psi) pressure range, resulting in 0.27 kPa (0.04 psi/bit) resolution, so a sustained 3 bit change is required to trigger a control function change. The sustained 3 bit change is required to filter out system noise or momentary pressure oscillations due to fluid motion. The system performance could be improved by increasing the word size to 16 bits, resulting in a 256 fold improvement in resolution. This is the approach used on SHOOT. The system could also be controlled by time rather than by pressure. The heat exchanger would simply be cycled at fixed intervals and the pressure response monitored.

Table 4.7.6-1 CONE Control Networks

CONTROL NETWORK	CONTROL NETWORK DESCRIPTION
C1 - PRESSURANT REGULATED PRESSURE CONTROL	PRESSURANT FLOW TO STORAGE TANK WILL BE TERMINATED BY CLOSING VALVES (V15A - V11B & V8B ARE BACKUP TO V15A) IF TANK PRESSURE SETPOINT IS EXCEEDED BY 5 PSIA.
C2 - STORAGE TANK CHX WARM SIDE OVER PRESSURE PROTECTION	CHX FLOW CONTROL VALVES (V12A &V13A) WILL OPEN WHEN CHX PRESSURE EXCEEDS 50 PSIA. VALVES WILL CLOSE WHEN PRESSURE DROPS BELOW 40 PSIA.
C3 - STORAGE TANK OVER PRESSURE PROTECTION	TANK PRESSURE IN EXCESS OF 45 PSIA WILL BE VENTED BY OPENING TANK VENT VALVES (V15A & V16A). VALVES WILL CLOSE WHEN PRESSURE DROPS BELOW 40 PSIA.
C4- STORAGE TANK PRESSURE CONTROL	CONTROL VALVE (V14A) FOR TVS HX WILL BE CYCLED TO MAINTAIN TANK PRESSURE TO A SPECIFIED SETPOINT LIMIT BETWEEN 15 - 40 PSIA.
C5 - TANK OUTFLOW LINE OVER PRESSURE PROTECTION	OUTFLOW LINE PRESSURE IN EXCESS OF 50 PSIA WILL BE VENTED BY OPENING OUTFLOW VALVE (V3B). THE VALVE WILL CLOSE WHEN PRESSURE DROPS BELOW 40 PSIA
C6 - STORAGE TANK TVS HX OVER PRESSURE PROTECTION	HX LINE PRESSURE IN EXCESS OF 50 PSIA WILL BE VENTED BY OPENING TVS CONTROL VALVE (V14A). VALVE WILL CLOSE WHEN PRESSURE DROPS BELOW 40 PSIA.
C7 - CHX VAPOR DETECTION FOR MIXER PUMP FLOW FLOW CONTROL	IF VAPOR IS DETECTED IN THE CHX DURING STORAGE TANK PRESSURE REDUCTION OPERATIONS THE MIXER PUMP WILL BE REDUCED TO MINIMUM SPEED. WHEN LIQUID IS DETECTED IN THE CHX THE PUMP WILL BE RETURNED TO OPERATING SPEED.
C8 - RECHARGE BOTTLE OVER PRESSURE PROTECTION	RECHARGE BOTTLE PRESSURE IN EXCESS OF 3200 PSIA WILL BE VENTED BY OPENING BOTTLE VENT VALVES (V9B & V10B). VALVES WILL CLOSE WHEN PRESSURE DROPS BELOW 3000 PSIA.
C9 - CHX/OHX FLOW WARM-UP CONTROL	POWER WILL BE APPLIED TO LINE HEATERS TO MAINTAIN CHX/OHX FLOW AS WARM GAS. POWER WILL BE TERMINATED IF LINE TEMPERATURE EXCEEDS 500 ° R
C10 - TVS FLOW WARM-UP CONTROL	POWER WILL BE APPLIED TO LINE HEATERS TO MAINTAIN TVS FLOW AS WARM GAS. POWER WILL BE TERMINATED IF LINE TEMPERATURE EXCEEDS 500 ° R
C11 - LN2 STORAGE TANK HEATER OVERTEMP CONTROL	POWER TO TANK WALL HEATERS WILL BE TERMINATED IF TANK PRESSURE EXCEEDS 45 PSIA.

5.0 PAYLOAD DESIGN

The carrier selected for CONE is a Hitchhiker Mission Peculiar Experiment Support System (MPESS) provided by GSFC. This carrier is termed a HH-M. The carrier is mounted in the Space Shuttle payload bay, probably in a forward location. The payload consists of an avionics subsystem assembly grouping atop the carrier and an experiment subsystem assembly grouping on the forward side of the HH-M. Thermal control and structural support elements also comprise the CONE payload flight system. Table 5.0-1 lists the major CONE assemblies and the weight, size, type of mounting, average power usage, and operating/storage temperature. Weights of those HH-M elements provided by GSFC are shown in parentheses.

Table 5.0-1 CONE Assemblies

ASSEMBLY	WEIGHT(EA) (LBS)	SIZE X(IN)		SIZE Y(IN)		SIZE Z(IN)	MPESS MOUNT	POWER (W)-AVE	TEMP STG	TEMP OP
•STORAGE TANK	148	23"D	X	40" TOTAL L (27.5" D X 46" TOTAL L) (W /VJ) (17" BARREL L, 11.5" DOME R W/O VJ)			DIRECT	043.0	-196°C TO 37.8°C	
•PRESSURANT BOTTLE (2)	015.2	14 IN. DIAMETER SPHERICAL TANKS					PLATE	000.0	-196°C TO 37.8°C	
•VALVE PANEL (2)	024/016	25.0"	X	39.0"	X	8.0" DEEP	PLATE	006.0	-196°C TO 37.8°C	
•EXPERIMENT VALVE ELECTRONICS	057	8.0"H	X	10.6"W	X	25.4"L	PLATE	033.0	-24°C TO 61°C	
•FLOW METER ELECTRONICS (3)	003	8.0"H	X	10.0"W	X	4.75"L	PLATE	007.5	-24°C TO 61°C	
•POWER DISTRIBUTION UNIT	010	5.5"H	X	7.5"W	X	8.25"L [SCI PDU]	PLATE	003.0	-24°C TO 61°C	
•CMD & DATA HANDLING UNIT •INCLUDES µPROCESSOR (S)	011	4.9 H	X	6.25"W	X	8.95"L	PLATE	012.2	-24°C TO +31°C OP -34°C TO +61°C ST	
•HITCHHIKER AVIONICS	(155)	24.0"H	X	24.0"W	X	12.0"L	PLATE	100.0	-24°C TO 61°C	
•HITCHHIKER-M MPESS	(1228)						P/L BAY	000.0		
HH-M SMALL PLATE (4)	56	25"	X	39"			MPESS	000.0		
HH-M TOP MOUNTING PLATE (2)	51.3	25"	X	36"			MPESS	000.0		
HH-M BRIDGE ATTACHMENT FITTINGS	(418)						P/L BAY	000.0		
•TANK AND BOTTLE MOUNTINGS										

Figure 5.0-1 shows the CONE payload mounted on the HH-M carrier.

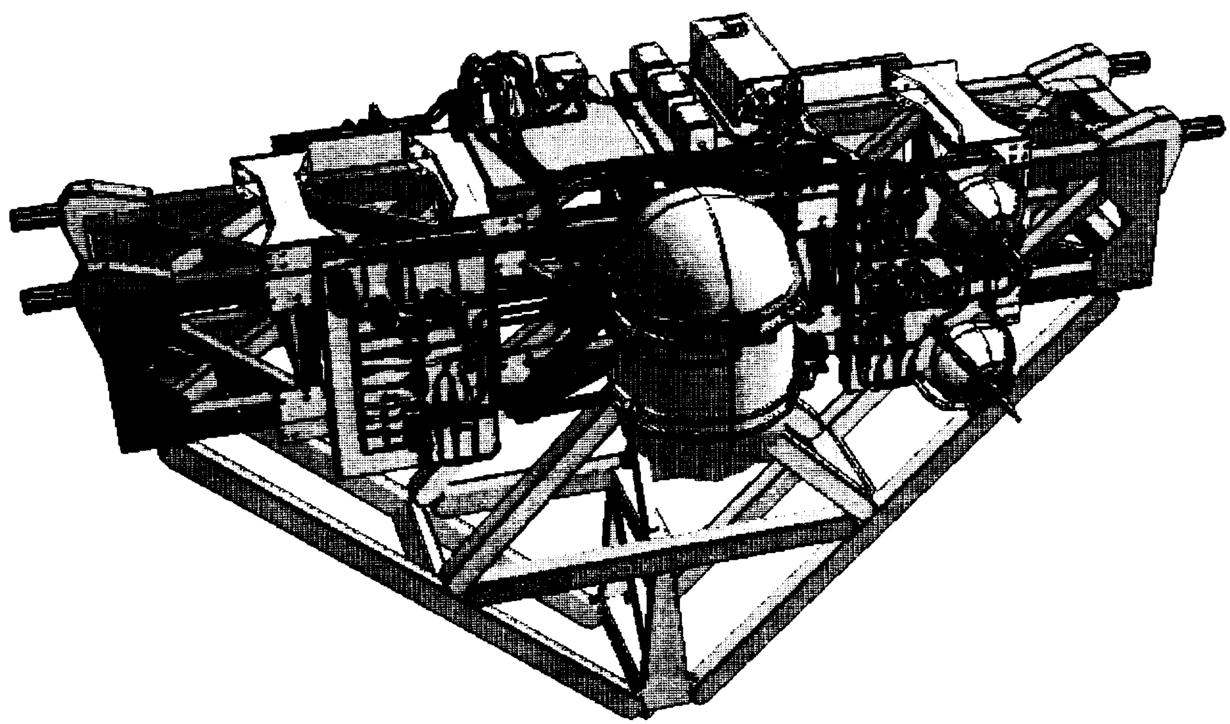


Figure 5.0-1 CONE Payload Mounted on the HH-M Carrier

The avionics are mounted to two Hitchhiker-provided top plates. The avionics are centered on the two inner-most attachment areas. The avionics for CONE are partitioned into the following functional areas: command and data handling (C&DHS), power distribution and fusing, experiment valve electronics (EVE), experiment sensor electronics, and heater control (contained within the EVE). The interfaces with the Shuttle, Hitchhiker, and GSE with the avionics are shown in Figure 5.0-2.

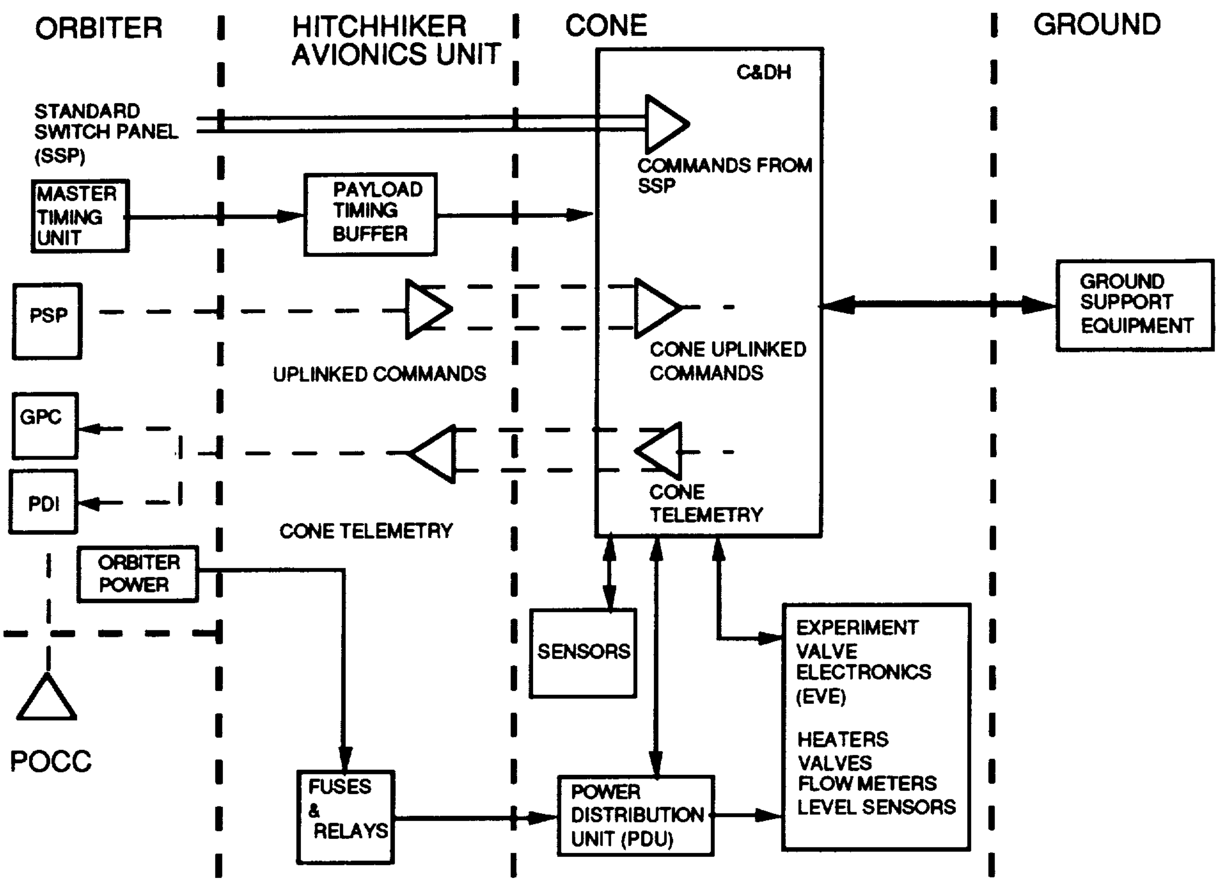


Figure 5.0-2 CONE Avionics Interfaces

The method of operation for CONE consisting of using crew initialization and then an automatic program, with crew involvement only to orient the Orbiter and to fire thrusters to achieve proper fluid orientation while also providing ground control of the experiment by use of contingency command uplinks only, if required. Selection of this operational approach minimizing the crew involvement in monitoring and commanding by requiring internal payload sequencing with some uplinking from the ground. To maximize the experiment return, changes to the flight sequence should be allowable, thus requiring ground intervention capability.

The C&DHS consists of a single unit. The data handling unit will contain a remote interface and a microprocessor for control of the experiment. The command and data handling is simplified by using the Hitchhiker asynchronous data links for both uplink and downlink. This requires a separate pickoff of the data stream in a PCM format if Shuttle safety or the crew requires knowledge of CONE data in the General Purpose Computer (GPC). This can be accommodated by the CONE C&DH subsystem.

The power distribution system interfaces with the orbiter fuel cells through the Hitchhiker Avionics Unit. The power distribution subsystem consists of one unit containing relays and fuses. Fault protection protects the bus and includes diode isolation, fuses, and low voltage detection. A single point ground concept is used. Power is fed from the shuttle fuel cell to the carrier using standard payload connections in the orbiter bay. The payload is required to provide circuit protection (fuses).

Communication, if required with the crew is through the General Purpose Computer (GPC). CRT data indications can be provided to the (GPC) on the Orbiter for display to the crew for those indications the crew is interested in seeing. Crew CONE commanding also uses the Standard Switch Panel (SSP) on the Aft Flight Deck.

The EVE contains the experiment subsystem valve driver circuits and heater controls. Electronics for flow meters and the mixer pump are required for flow meter power and data conditioning and pump power conditioning. The electronics are vendor-provided with the sensors and mixer pump. Since the EVE is an element that is a derivative of an existing design, modifications could incorporate these miscellaneous electronics. This activity is recommended for follow-on phase C/D efforts.

A separate power bus is provided by the power distribution unit (PDU), powered through a separate set of relays, to enable control of the experiment power separate from the command and data handling subsystem. All buses are unregulated 28 Vdc.

The cabling shown on the GEOMOD drawing in Figure 5.0-3 is a representation of the CONE cabling. The Hitchhiker program office provides all of the interface cabling to the Hitchhiker Avionics Unit. Cabling from the valve panels and the tank are routed to the top of the valve panels and terminated in connectors. This allows for a complete harness assembly for each experiment subsystem module and the LN2 storage tank so that interfacing to avionics subsystem power and command and data harnesses can be easily effected.

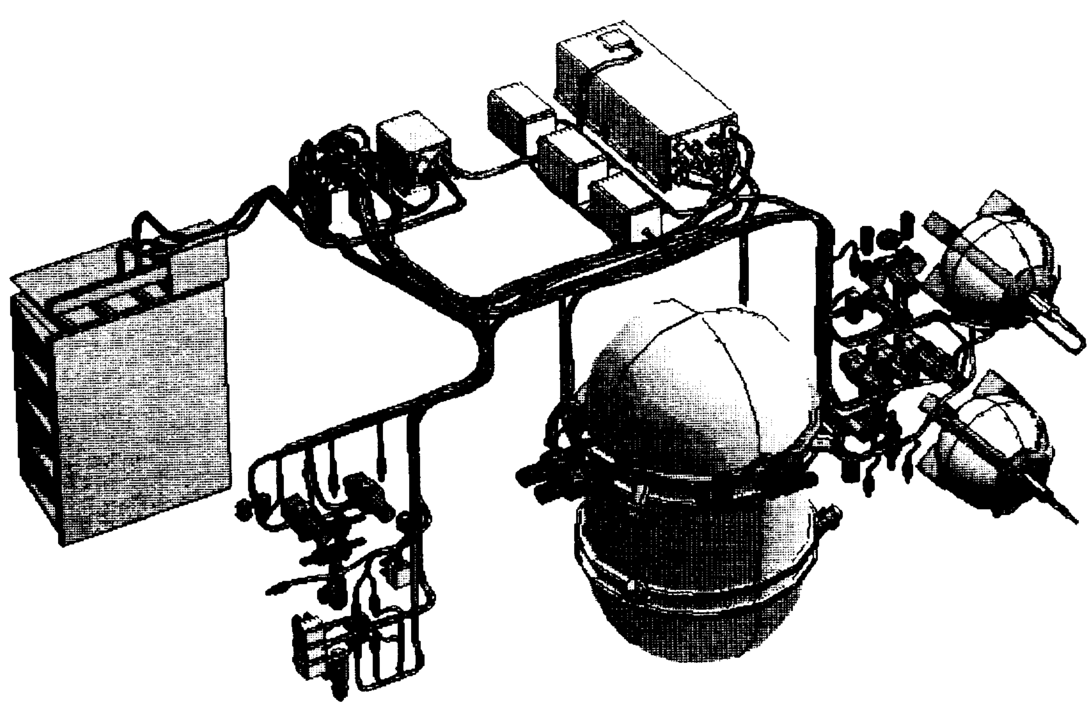


Figure 5.0-3 CONE Cabling

All CONE drawings reference the Shuttle coordinate system. The center-of-gravity calculations will use the Shuttle coordinate system when the manifest determines the location of the payload in the bay. Until then, the x dimension will reference the carrier C/L. The orientation with respect to the shuttle can be determined using the diagram in Figure 5.0-4. The shuttle axes and the HH-M axes are used to list the mass properties. The payload is mounted in the Shuttle such that when in the liftoff position on the pad, the payload storage tank is above the MPESS with the long axis of the tank in the Orbiter Z direction.

The interface mounting points of the payload to the carrier are normally those to the Hitchhiker mounting plates. The exception is the mounting of the storage tank, which, because of its size and weight, requires special attachments. The mechanical components consist of plumbing attached to two side mounted plates (the valve panel assemblies), with the storage tank attached to the HH-M between the valve panel assemblies. CONE Plumbing is depicted in Figure 5.0-5.

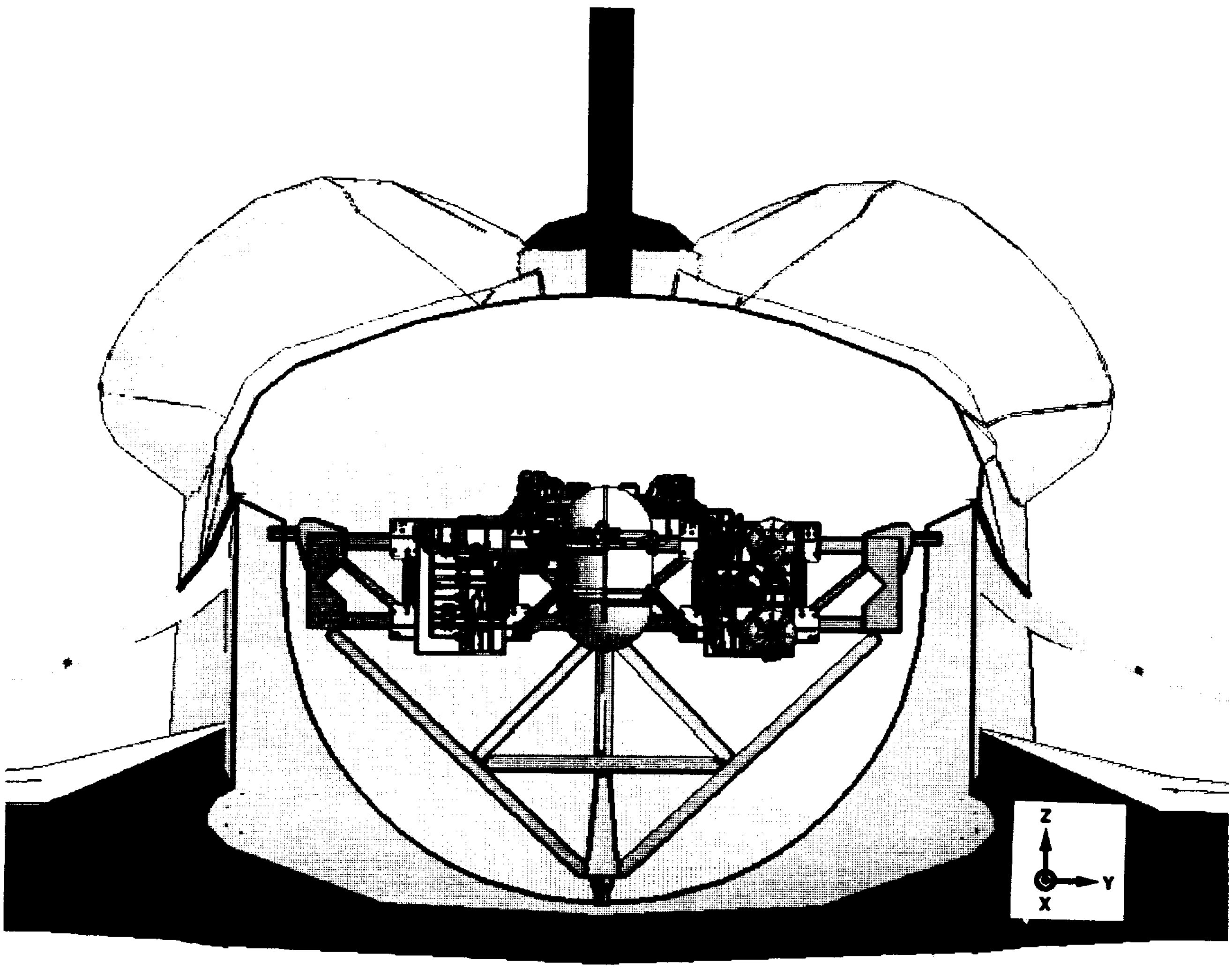


Figure 5.0-4 CONE Orientation in the Shuttle Bay

Each valve panel assembly is mounted on a fiberglass composite plate which in turn is mounted to a Hitchhiker-M provided plate. The storage tank is mounted with attachment hardware at three points. Monoballs are used in the attachment hardware to allow for shifting forces.

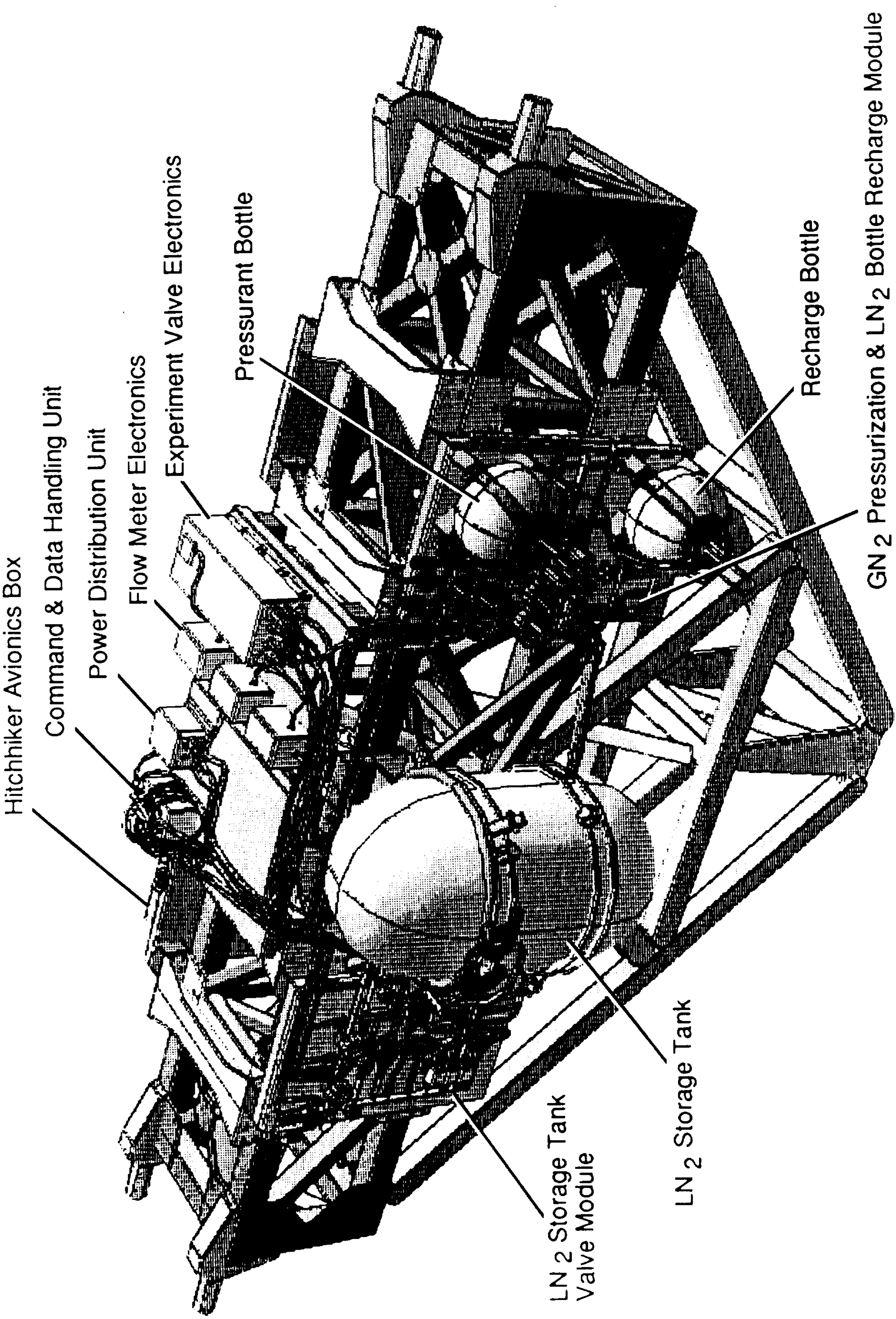


Figure 5.1-1 CONE Baseline Configuration

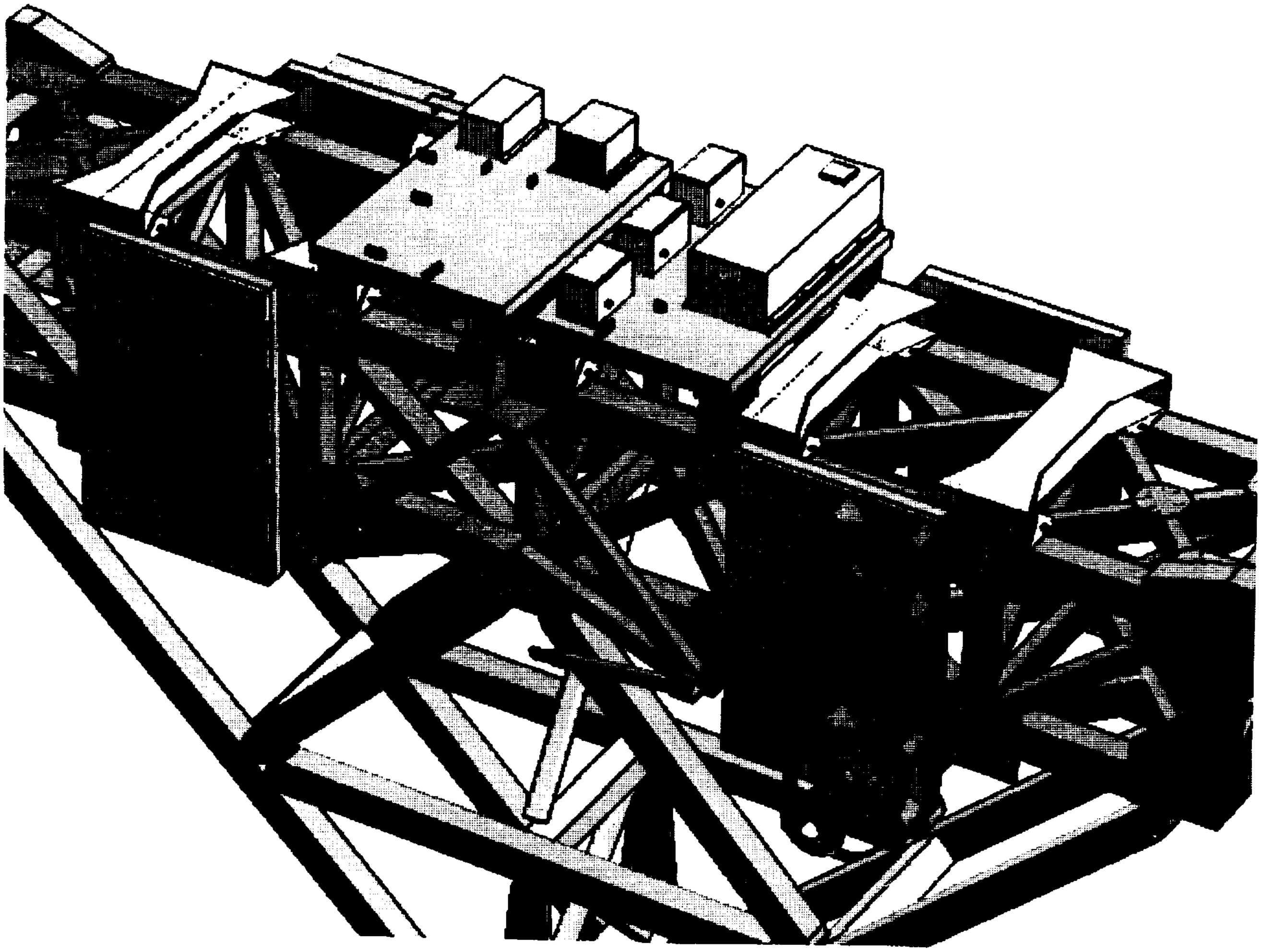


Figure 5.2-1 CONE Structural Mounting Hardware on the MPESS

The LN2 storage tank is too heavy to attach to the MPESS using the standard Hitchhiker-provided attachment plates. Therefore, another method was selected to attach to the MPESS. Utilizing the center MPESS structure and the thermal isolators provided by Hitchhiker (GSFC), the structure requires a three point attachment. The storage tank mounting was devised in order to accommodate the weight of the tank plus the LN2. Storage tank structural attachment hardware is thermally isolated from the MPESS to avoid thermal distortion by the use of the same attachment hardware hitchhiker uses behind the attachment plates. Interface tubing connects the valve panels with the storage tank. Supports for this tubing are also required. The CONE design uses standard Hitchhiker attachments for the avionics for CONE. These standard attachments are top and side mounted plates. There are no interfaces to the MPESS or the Shuttle for the fluid system. The vents are used to dump directly to space or into the cargo bay. The fluid components mount to fiberglass valve panels which then interface with Hitchhiker side mounting plates. Foam and MLI covering the valve panels and the avionics will interface with the Hitchhiker top and side plates. All Hitchhiker plates have attachment hardware to thermally isolate the MPESS structure from the payload.

Mass Properties - The mass properties in Table 5.2-1 were calculated using the GEOMOD program. They are defined from the baseline layout of hardware. The cg in the x axis is based on the MPESS CG because the location in the Shuttle bay is unknown until after manifesting. The ideal cg points are the MPESS CG for x, the Shuttle bay centerline for y, and the MPESS trunnion attach points for z. The GSFC has requested that the cg be between the trunnion points in x to be able to maximize the payload weight.

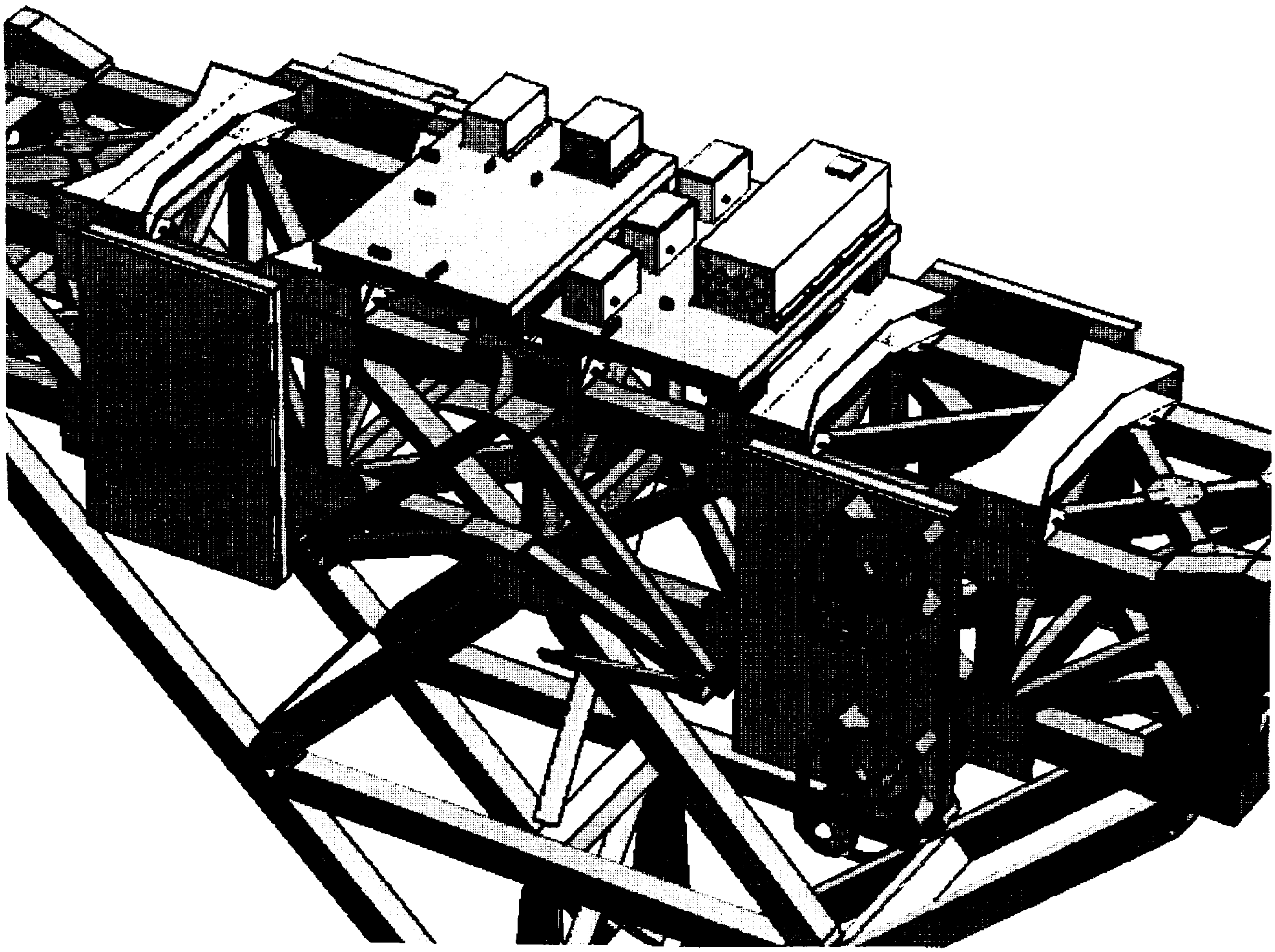


Figure 5.2-1 CONE Structural Mounting Hardware on the MPESS

The LN2 storage tank is too heavy to attach to the MPESS using the standard Hitchhiker-provided attachment plates. Therefore, another method was selected to attach to the MPESS. Utilizing the center MPESS structure and the thermal isolators provided by Hitchhiker (GSFC), the structure requires a three point attachment. The storage tank mounting was devised in order to accommodate the weight of the tank plus the LN2. Storage tank structural attachment hardware is thermally isolated from the MPESS to avoid thermal distortion by the use of the same attachment hardware hitchhiker uses behind the attachment plates. Interface tubing connects the valve panels with the storage tank. Supports for this tubing are also required. The CONE design uses standard Hitchhiker attachments for the avionics for CONE. These standard attachments are top and side mounted plates. There are no interfaces to the MPESS or the Shuttle for the fluid system. The vents are used to dump directly to space or into the cargo bay. The fluid components mount to fiberglass valve panels which then interface with Hitchhiker side mounting plates. Foam and MLI covering the valve panels and the avionics will interface with the Hitchhiker top and side plates. All Hitchhiker plates have attachment hardware to thermally isolate the MPESS structure from the payload.

Mass Properties - The mass properties in Table 5.2-1 were calculated using the GEOMOD program. They are defined from the baseline layout of hardware. The cg in the x axis is based on the MPESS CG because the location in the Shuttle bay is unknown until after manifesting. The ideal cg points are the MPESS CG for x, the Shuttle bay centerline for y, and the MPESS trunnion attach points for z. The GSFC has requested that the cg be between the trunnion points in x to be able to maximize the payload weight.

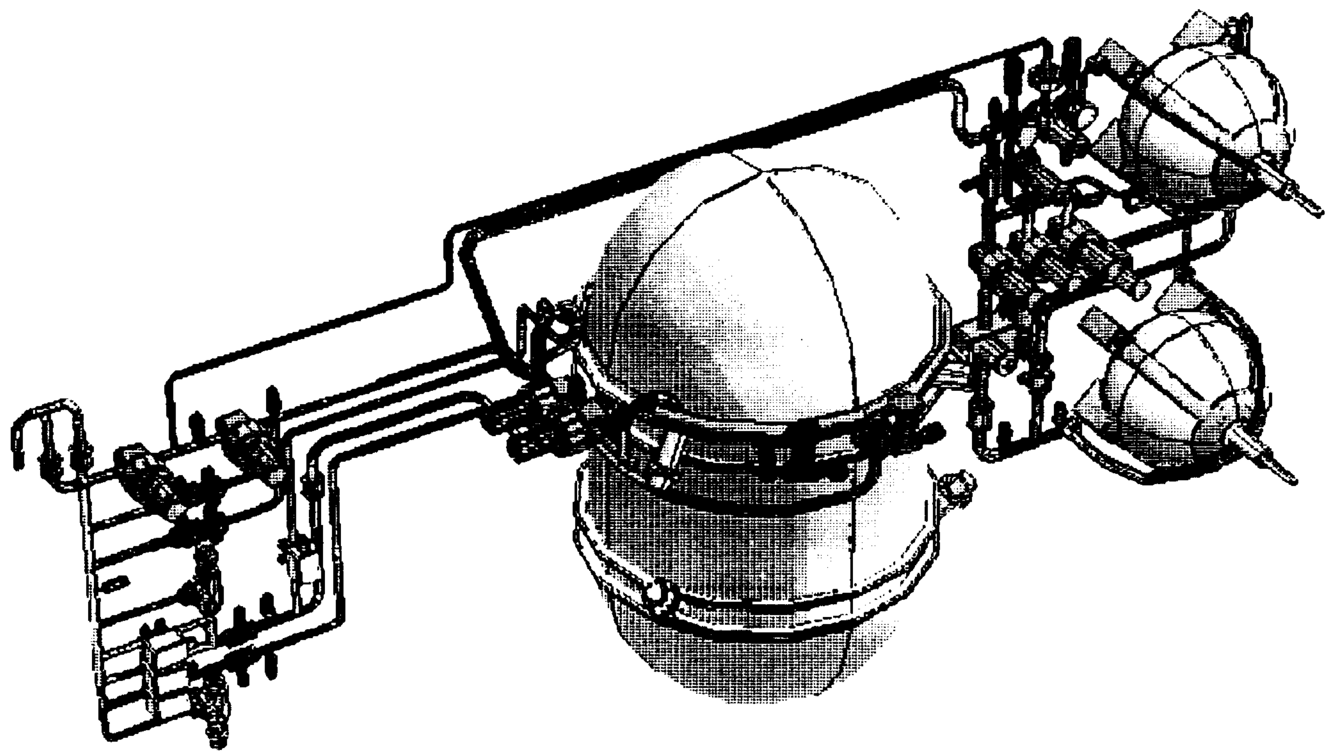


Figure 5.0-5 CONE Plumbing

Table 5.2-2 CONE Component Mass Properties and Subsystem Mass Allocations (Concluded)

SUBSYSTEM	# OF UNITS	MASS PER UNIT	MASS (LBM) NO MARGIN
STRUCTURE			**90.0**
TANK A SUPPORT	1	20.0	20.0
PRESSURANT TANK SUPPORT	2	5.0	10.0
EXPERIMENT ENCLOSURE	1	60.0	60.0
C&DHS			**11.0**
COMMAND & DATA HANDLING UNIT <WITH MICROPROCESSOR>	1	11.0	11.0
TOTAL DRY WEIGHT			**517.9**
CONSUMABLES			**396.8**
SUPPLY TANK LN2	1	375.0	375.0
GASEOUS NITROGEN PRESSURANT	2	10.9	21.8
TOTAL EXPERIMENT WEIGHT			**914.7**
MARGIN (20% ON DRY WEIGHT)			**103.6**
TOTAL EXPERIMENT WEIGHT (WITH MARGIN)			**1018.2**
HITCHHIKER PROVIDED			**2121.0**
HITCHHIKER MPESS STRUCTURE	1	1646.0	1646.0
HITCHHIKER-M AVIONICS (C&DH,TIMING,PWR)	1	155.0	155.0
HH TOP PLATE	2	50.0	100.0
HH I/F PLATE (AVIONICS UNIT)	1	55.0	55.0
HH SIDE I/F PLATE (VALVE PANEL)	1	55.0	55.0
HH SIDE I/F PLATE (EXP AVIONICS)	2	55.0	110.0
TOTAL LAUNCH WEIGHT (WITH MARGIN)			**3139.2**

The preliminary design limit load factors shown are specified in the Hitchhiker Shuttle Payload of Opportunity Carrier Customer Accommodations and Requirement Specification, HHG-730-1503-05 document. These loads are generalized loads that envelope the worst case steady state, low frequency transient, and higher frequency vibroacoustic launch and landing environments. Final flight limit loads will be derived from the manifested STS Coupled Loads Analysis.

The load factors include an uncertainty factor of 1.1 and are considered as positive and negative and combine in all possible combinations. All accelerations are applied through the payload center of mass using the STS coordinate system. The limit load factors for Hitchhiker payloads are 11.0 g in each axis and the angular acceleration is 85.0 radians per second squared in each radial axis. Any thermally induced loading will be combined with the above loads. All flight hardware will be designed and analyzed for structural integrity and safety to meet Safety Policy and Requirements for Payloads Using the Space Transportation System, NSTS 1700.7B. The structural analyses included design factors of safety shown in Table 5.2-3. Final analyses will include the effects of weld residual and mismatch stresses (0.08 cm (0.03 inch) maximum).

The CONE tank will be designed and tested to meet the mandatory requirements of Standard General Requirements for Safe Design and Operations of Pressurized Missile and Space Systems, MIL-STD-1522A. The inner tank design conditions occur with the maximum cold temperature of LN2 due to increased material properties at the cold condition. This cold condition occurs during the on-orbit, launch and abort landing conditions only. The inner tank leak test condition has a critical pressure of -138 kN/m^2 differential (-20 psid) which combines with preload and the one g load. The inner tank on-orbit condition has a critical pressure of 345 kN/m^2 differential (+50 psid) which combines with preload and thermal loads. For launch and landing conditions, the inner tank critical pressure is 138 kN/m^2 differential (20 psid) which combines with preload, inertial and thermal loads. In order to reduce testing, a factor of safety of 4.0 produces a critical pressure of 1380 kN/m^2 (200 psid). The outer tank critical design condition of -138 kN/m^2 differential (-20 psid) occurs during the launch and abort landing condition and combines with preload and inertial loads.

Table 5.2-3 Design Factors of Safety

LOAD	FACTOR OF SAFETY	
	YIELD	ULTIMATE
INERTIAL	1.35	1.4
PRELOAD STRAP	1.0	1.0
THERMAL LOADS	1.0	1.0
FITTING FACTOR-MECHANICAL JOINTS	1.15	1.15
STABILITY FACTORS-CRITICAL MEMBERS	-	1.15
TANK (STRUCTURAL)	1.35	1.4

The CONE tank support assembly has a statically determinate structural interface to the MPESS. One Hitchhiker-like monoball is used as the upper attachment support . Two truss type supports with monoballs along with one restraint in the Y direction of the STS coordinate system are used at the lower attachment. The support concept is simple, lightweight, and the tank and support can be installed as a single unit. The supports, however, are stiffness critical. Local loads are on the girth rings for the outer tank and at the shell/strap interface for the inner tank. Figure 5.2-2 depicts the tank structural mounting.

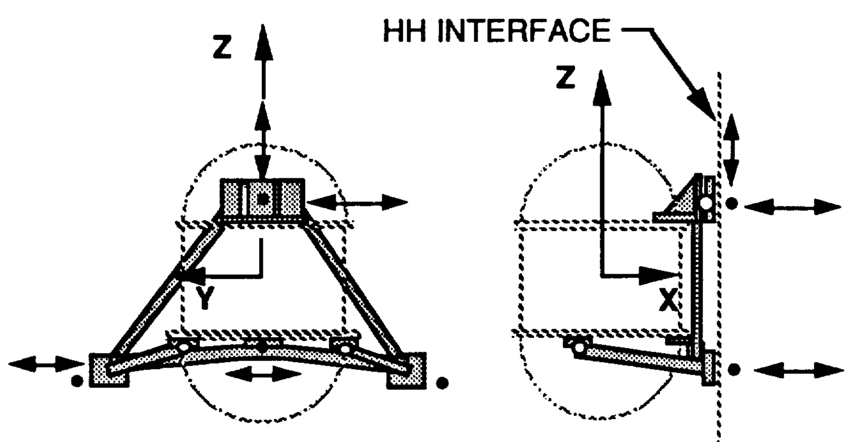


Figure 5.2-2 Tank Structural Mounting

A finite element model of the CONE tank was created using the SDRC I-DEAS Supertab module. After the mesh was generated in Supertab, a MSC/NASTRAN finite element model was created. The pressure vessel and vacuum jacket were both modeled with quadrilateral and triangular plate elements. The plate thickness was varied to represent local stiffening of both tanks. Bar elements were used to represent the straps and the interface struts to MPESS. Rigid elements were used to beam the strap loads to the vacuum jacket. The liquid nitrogen mass was incorporated into the model by smearing non-structural mass on the pressure vessel plate elements. The model contains 907 grid points. After

The subsystem allocations shown in Table 5.2-2 are derived from the weights of the baseline components. The 20% margin used allows for sufficient growth potential. Margin is contained within the allocated 170 kg (375 lb) of LN2. Carrier weight is not included in the payload allocation, but is listed separately. Attachment hardware plates are charged to the payload, except for the attachment plate for the Hitchhiker avionics unit.

The Hitchhiker User's Guide lists an artificial 545 kg (1200 lb) as the maximum weight for Hitchhiker-M payloads. Discussions with the Hitchhiker Program Office at GSFC indicated that weight and cg are negotiable up to 2091 kg (4600 pounds). The amount over the 545 kg (1200 lb) limit is due, in part, to the heavy attachment plates Hitchhiker provides, and to the amount of LN2 carried. The addition of a transfer experiment, with a receiver tank and associated plumbing, will add another 52.7 kg (116 pounds) (including margin) to the payload.

Table 5.2-1 CONE Component Mass Properties

PAYLOAD MASS (CONE & HH-M)	3139 LBS
CENTER OF GRAVITY (WITHOUT MPESS STRUCTURE)	
X	=43.2 CM(17 IN) ABOVE MPESS CG
Y	=10.2 CM(4 IN) LEFT OF SHUTTLE BAY C/L
Z	=25.4 CM(10 IN) BELOW MPESS TOP
(TRUNNIONS ARE AT Z=414)	TRUNNION ATTACH POINTS
MOMENTS OF INERTIA OF P/L (WITHOUT MPESS)	
I(XX)	=2.3X10(E8)
I(YY)	=3.3X10(E6)
I(ZZ)	=2.3X10(E8)
PRODUCTS OF INERTIA OF P/L (WITHOUT MPESS)	
I(XY)	= -9.2 X10(E5)
I(YZ)	= 1.7 X10(E7)
I(XZ)	= 2.5 X10(E5)
(WITH RESPECT TO SHUTTLE AXES)	

The cg for the CONE payload changes over time due to the movement of the consumables (LN2 and GN2). Y and Z change less than 2.5 cm (1 in) over the mission. The X axis cg shifts and liquid is removed from the storage tank and when the recharge bottle is emptied and then filled with liquid. The x axis shift moves 15.2 cm (6 in) over the mission.

Stress and Dynamics - The payload structure stiffness requirements are specified in the Hitchhiker Shuttle Payload of Opportunity Carrier Customer Accommodations and Requirement Specification, HHG-730-1503-05 document. This document requires an analysis, either classical or finite element, of the lowest natural vibration frequency of the payload components hard-mounted at the interface.

Finite element math models of payload components are required to be submitted to GSFC for components which have a lowest natural frequency of less than 50 Hz. A finite element math model is not required for components with lowest natural frequency greater than 50 Hz unless deemed necessary by GSFC. The finite element math model can be verified by modal survey, sine sweep, vibration or impact test.

orbit condition has a critical pressure of 345 kN/m^2 differential (+50 psid) which combines with preload and thermal loads. For launch and landing conditions, the inner tank critical pressure is 138 kN/m^2 differential (20 psid) which combines with preload, inertial and thermal loads. In order to reduce testing, a factor of safety of 4.0 produces a critical pressure of 1380 kN/m^2 (200 psid). The outer tank critical design condition of -138 kN/m^2 differential (-20 psid) occurs during the launch and abort landing condition and combines with preload and inertial loads.

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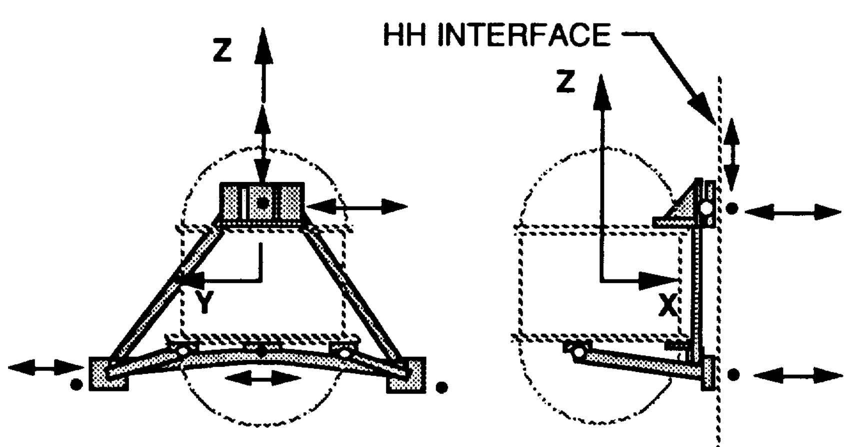

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5.3 External Thermal Control

Thermal Requirements - The purpose of the preliminary thermal analysis was to determine the feasibility of the baseline configuration. Requirements have been established and a preliminary design concept evaluated. Six basic goals for a desirable thermal design concept were identified. These are maintaining components within flight allowable ranges, using a passive thermal design with heaters, minimizing heater requirements, imposing no Shuttle orientation constraints from the thermal requirements, having a nominal heat flux transfer through the storage tank vacuum jacket of 1.43 w/m^2 (0.45 BTU/hr/square foot), and minimizing the thermal transient lag time for warming of the recharge bottle. Foremost of course, is the need to keep the components within their allowable temperature ranges. In addition, it is very desirable to refrain from using any active thermal control devices, other than thermostatically controlled heaters. The goal is to have as simple a thermal control design as is adequate.

The heater power requirements are restricted to the available bus power provided by the shuttle. There are 6 ports, each providing 50 watts of power, available. Only as many ports as necessary should be used. Additionally, Hitchhiker payloads are required to withstand any shuttle orientation.

Temperature margins are applied to thermal analysis predictions in accordance with MIL-STD-1540B Test Requirements. An uncertainty margin of 11° C (20° F) is applied to the component temperature predictions as obtained with the thermal math model. This margin is intended to compensate for uncertainties in parameters such as complicated view factors, surface properties, contamination, radiation environment, joint conduction, and inadequate ground simulation. The resulting temperature prediction (including the uncertainty margin) must fall within the flight allowable temperature range. If the component is actively heated, then the uncertainty margin is not needed on the cold end. However, the heater must be oversized by 25%. This margin is confirmed by achieving heater duty cycles ≤ 80%.

The components are acceptance tested at the flight allowable temperature extremes. A ±5°C (9°F) test margin is applied to the flight allowable temperature range for protoflight qualification. Protoflight hardware is used for both qualification testing and as flight hardware. Therefore, the protoflight qualification test margin is less severe than the prototype (dedicated qualification test unit) qualification test margin. The CONE program will use protoflight hardware.

Environments Imposed on the Payload - One of the requirements for Hitchhiker payloads is that no constraints be imposed on the shuttle orientation. The hottest environment for a shuttle payload is that of the 3 axis inertial +ZSI, bay facing sun orientation. The coldest payload environments occur during a bay to space shuttle orientation. The shuttle can tolerate the +ZSI orientation for up to 160 hours. The +XSI bay to space orbital orientation (shuttle revolves around the X axis at the orbital rate) can only be tolerated 6 to 7 hours for Beta angles less than 60°. However, the shuttle limitation for this orientation is not based on a cold concern, but rather, on the hot case temperature limit of a component located on the aft end of the shuttle. Another cold case orientation that is essentially as cold as +XSI, orbital is that of -XSI, bay to space with the nose pitched up 10°. The shuttle can tolerate this orientation for up to 160 hours for Beta angles less than 20°, although it can only tolerate 7 hours for Beta angles between 20° and 60°. Since every possible orientation of the shuttle can not possibly be included in the ICD, a cold extreme case cannot be clearly identified. A slight alteration in the position of the shuttle could result in an orientation that is just as cold, but allows a longer duration period. From the payload's perspective, all bay to space orientations are essentially equivalent. Therefore, it is concluded that in order not to constrain the shuttle, the payload should be able to withstand up to 160 hours of bay to space exposure.

There are two standard nominal shuttle orientations. These are +ZLV (bay facing earth) and PTC (passive thermal control maneuver). The +ZLV orientation is considered the standard shuttle orientation. Unless required by the mission, the shuttle will normally stay in this orientation. The PTC maneuver is used for thermal conditioning. It consists of rotating around the X axis in a barbecue fashion. It is the most thermally benign of the shuttle's orientations. Also included in the chart are the allowable durations for the other five 3 axis solar inertial orientations. This data, as well as that for the other orientations given in the ICD, is useful for determining whether a desired orientation would be permitted by the shuttle.

The preliminary thermal analysis for CONE encompassed three environmental cases. These are 1) the worst hot case, +ZSI; 2) the worst cold case, +XSI, bay to space orbrate; 3) the nominal case, +ZLV. The thermal design for CONE will be verified (by thermal vacuum test) by confirming that the payload can withstand indefinite exposure (or up to 160 hours) to any of these environments.

The worst case hot environment chosen for analysis is a 3 axis solar inertial orientation where the shuttle bay is always facing the sun. Three beta angles were evaluated, 0°, 60°, and 90°. In the 90° beta angle case, the shuttle is exposed to the sun throughout the entire orbit. It represents the hottest environment. For beta angles less than 90°, the shuttle will have an eclipse portion of the orbit, where the earth obstructs the solar radiation. As the beta angle decreases, the length of the eclipse duration increases.

The worst case cold environment chosen for analysis is a +XSI orbrate maneuver with the shuttle bay to space. The shuttle rotates around the X axis at the rate of one revolution per orbit such that shuttle bay (+Z) faces away from earth toward space. The tail of the shuttle always faces the sun. Thereby, the solar radiation is shaded by the tail and the shuttle bay is exposed to primarily deep space. Again, three beta angles, 0°, 60°, and 90° were evaluated. The longer duration of the eclipse portion of the orbit causes the 0° beta angle case to be the worst case cold environment.

The shuttle normally maintains an orientation with the bay facing earth. This case represents a nominal thermal environment for the payload. The shuttle orbits around the earth with the +X axis in the direction of the orbital vector. The Y axis is perpendicular to the orbital plane. The +Z axis maintains a direction toward earth such that the shuttle bay views earth.

The passive thermal control maneuver is used for thermal conditioning of the shuttle. The shuttle rotates around the X axis at a rate of 2 to 5 revolutions/orbit. Also known as a barbecue maneuver, this rotation provides more evenly distributed solar and earth fluxes incident on the shuttle No single component will remain in an extreme thermal environment for an extended period of time. Since the thermal response of a spacecraft in the shuttle orbit is of a very transient nature, this orientation is the most benign. This environment has not been used for preliminary analysis purposes other than for initialization of the other environment analyses.

The CONE components are protected by the CONE thermal control system which is shown in Figure 5.3-1. Solar entrapment occurs in the shuttle bay. Thus, components situated lower in the bay experience higher temperatures. For this reason, it is desirable to have the heat dissipating avionics components located on top of the Hitchhiker MPESS structure for better heat rejection capability. Less heat is absorbed in this location, and more heat can be radiated to space. The components are attached to I/F plates that are provided by the Hitchhiker carrier. These plates will be painted white. White paint provides good solar heat rejection (low solar absorptivity) and excellent IR heat rejection (high IR emissivity). The cryogenic components are attached to the side of the MPESS structure. MLI is used on the side I/F plates so that the plates are insulated from the extreme temperatures of the bay liner. The Hitchhiker avionics box is a Hitchhiker provided component. Its thermal design will be established by Goddard Space Flight Center.

The C&DH (Command and Data Handling Unit), the PDU (Power Distribution Unit), and the three FMEs (Flow Meter Electronics) will be insulated from the environment with MLI (multi layer insulation). MLI, commonly referred to as "a thermal blanket" consists of a layered series of highly orientation. Unless required by the mission, the shuttle will normally stay in this orientation. The PTC maneuver is used for thermal conditioning. It consists of rotating around the X axis in a barbecue fashion. It is the most thermally benign of the shuttle's orientations. Also included in the chart are the allowable durations for the other five 3 axis solar inertial orientations. This data, as well as that for the other orientations given in the ICD, is useful for determining whether a desired orientation would be permitted by the shuttle.

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The C&DH (Command and Data Handling Unit), the PDU (Power Distribution Unit), and the three FMEs (Flow Meter Electronics) will be insulated from the environment with MLI (multi layer insulation). MLI, commonly referred to as "a thermal blanket" consists of a layered series of highly applying the appropriate reduction transformations and constraint elimination, 5314 elastic degrees of freedom remained. The boundary conditions represented the actual interface between the CONE tank support structure and the MPESS truss. The +Z interface location is fixed in three translations and free in three rotations. The +Y and -Y interfaces are fixed in XY and X respectively with the rotations free.

To determine the CONE natural frequencies and understand how the structural system interacts dynamically, a normal modes solution was used to compute the modes. Various combinations of strap thickness, local plate reinforcement of the tank mounting points and support structure section properties were incorporated into the model. The model solutions were then examined for frequency content and weight. Model strain energy and mode shapes were studied in detail to determine model modifications to minimize weight and maximize stiffness. The model exhibited lateral motion of the mass of the LN2 and pressure vessel tank. The stiffness for these modes are provided by the interface straps and local tank reinforcement. The first three fundamental modes are at frequencies of 41, 48.3 and 52.3 Hz with pressure vessel lateral motion in Y, X, and Z respectively. It is expected that the system will exhibit torsion of the pressure vessel mass on the support straps. An accurate value of the strap bending stiffness is not currently available. The torsional stiffness of the pressure vessel/strap system varies with displacement (non-linearly) and requires further analysis.

The maximum internal pressure for the inner tank was assumed equal to the sum of internal pressure of 1380 kN/m^2 (200 psi), which includes ultimate factor of safety of 4.0, and hydrostatic pressure in 11 g environment - 117 kN/m^2 (17 psi). Total maximum internal pressure used in analysis was 1497 kN/m^2 (217 psi). The tank PV and VJ are formed from 2219-T852 aluminum and machined to the final dimensions.

The tank shell structural analysis was performed for a combination of pressure load and local stress due to strap preload. This load combination will require local increase in the tank shell thickness on the shell/strap lug interface. Shell thickness will be tapering off toward the membrane zone of the tank. Lug location is assumed to be outside of the girth weld heat affected zone, which has annealed material properties. To maintain the structural integrity of the cylindrical and spherical sections of the tank, tapered zones are provided also in the girth weld area due to annealed material properties.

The tank minimum gage and margins of safety due to the internal pressure are shown in Figure 5.2-3. The margins shown are the minimum values manually calculated from multiple sources for analysis of thin walled cylinders and thin spherical shells under internal pressure and local loads. Among the references used were the Astronautics Structures Manual and the Formulas for Stress and strain by

TANK AREA	MINIMUM THICKNESS INCHES	ULTIMATE MARGIN OF SAFETY
INNER DOME (SHELL/STRAP LUG I/F)	0.1875	+0.23
INNER DOME (MEMBRANE)	0.075	+1.93
INNER DOME (GIRTH WELD)	0.1875	+1.50
INNER CYLINDER (MEMBRANE)	0.075	+1.47
INNER CYLINDER (GIRTH WELD)	0.1875	+0.46

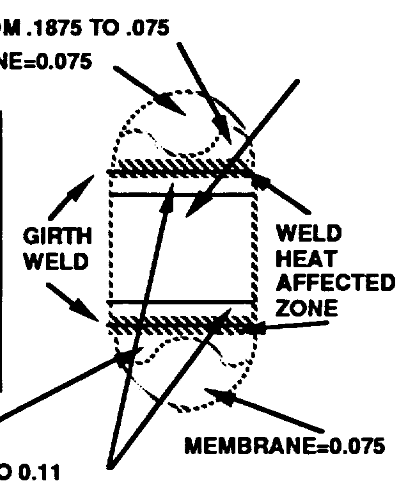

Figure 5.2-3 Tank Margins of Safety Due to Internal Pressure

Only two heaters will be required to maintain the component temperatures within limits. These are on the EVE and on the PDU. These components require heaters because of their high 0°C (32 °F) minimum temperature limit. Since they also have a restrictive maximum temperature limit 36 °C (124 °F), and they dissipate electronic heat, their thermal design is intended to reject heat. The EVE is uninsulated and the PDU is conductively coupled to the I/F plate. Consequently, the size of the heaters is increased. In addition, MIL-STD-1540B requires a 25% oversize of the heaters. The thermostat set points are based on the minimum allowable temperature. A 5.6 °C (10 °F) differential range is normal for flight heaters, and a tolerance of ±1.7 °C (3 °F) can be expected.

The thermal analysis was conducted with a TRASYS model and a SINDA 85 model. TRASYS is a thermal radiation analysis program, developed by Martin Marietta, used to determine geometric view factors. The CONE TRASYS model consisted of 13 nodes. SINDA 85 is a finite difference thermal analyzer program also developed by Martin Marietta. It solves lumped parameter network representations of systems for temperature predictions. The CONE SINDA model was approximately 26 nodes. These are relatively simple models. Phase B will use more refined TRASYS and SINDA models for the solving of CONE's thermal responses. Also utilized for this preliminary analysis were NASA's existing 136 node TRASYS and SINDA models of the shuttle.

The orbital parameters used are slightly more conservative than those provided in the ICD. The beta angle was assumed to be ≥ 0° and ≤ 90°. Actually, the CONE payload is requesting a constraint of the beta angle to be ≤ 60° for high drag requirements for LN2 settlement. Beta angles ≤ 60° are standard for shuttle missions.

The Hitchhiker carrier was not included in this preliminary thermal analysis. Only the I/F plates were modelled. These plates were assumed isolated from the carrier both radiatively and conductively. For this stage of the analysis, assumptions were made for the thermophysical properties and the conductive network. Conservative values were chosen based on experience. The Phase C/D thermal analysis will use more precise calculations when constructing the thermal math model.

Temperature predictions for major CONE elements were during the cold and hot worse case environmental conditions for three assumed beta angles which are 0°, 60°, and 90°. A 90° beta angle results in a greatly increased hot case temperature prediction. The hot case environment used in this thermal analysis was continuous ZSI. The cold case environment orientation used was continuous +XSI, bay facing space. The analysis runs were initialized with steady state PTC environment conditions. After approximately 20 hours, all components have essentially reached an equilibrium state. Only orbital variations occur. Table 5.3-2 shows the summary results of this analysis.

The results of the preliminary thermal analysis show that the baseline CONE configuration is acceptable thermally. The thermal design goals can be achieved. It is recommended that the shuttle be constrained to beta angles ≤ 60°. It is also recommended that the allowable temperature ranges for the PDU and the EVE be expanded to the MIL-STD-1540B standard range of -24 C (-11 F) to 61 C (142 F). This recommendation should be evaluated by an Avionics engineer during Phase C/D. There still exists much flexibility in the thermal control system design. The Phase C/D thermal analysis should optimize and refine these results.

5.4 Avionics Subsystem

Figure 5.4-1 is a block diagram of the CONE avionics showing the interfaces with the Hitchhiker Avionics Unit, the Shuttle avionics, and the GSE.

Electrical Power Subsystem (EPS) - The EPS controls, conditions, distributes, monitors and provides power bus isolation and protection. A Power Distribution Unit (PDU) provides protection, control and distribution of 28 vdc electrical power from the HH-M avionics unit to electrical elements on the payload. The PDU also provides power to the experiment mixer pump, heaters and valves via the

Experiment Valve Electronics (EVE) unit. Relays in the Power Distribution Unit will be used as drivers for valves and heaters and to switch bus power to the C&DH unit and the experiment electronics.

Table 5.3-2 CONE Thermal Analysis Results Summary

		0° Beta Angle		60° Beta Angle		90° Beta Angle	
	Flight Allowable °F	Temp. °F	Duty Cycle	Temp. °F	Duty Cycle	Temp.°F	Duty Cycle
Avionics Equipment							
C&DH	-11 to 142	8 to 115	---	14 to 117	---	16 to 141	---
EVE	32 to 124	39 to 95	77.2%	40 to 98	48.8%	40 to 119	38.0%
FME	-40 to 165	10 to 140	--	21 to 145	---	26 to 171	---
PDU	32 to 124	40 to 107	77.5%	40 to 107	40.4%	40 to 133	24.0%
Cryogenic Storage Components							
LN2	-320 Nominal	Temp	Held	Constant	as	Boundary	Node
GN2	-320 to 120	-8 to 79	---	13 to 83	---	20 to 107	---
LN2 Storage Tank	-100 to 150	-64 to 110	---	-29 to 101	---	-9 to 116	---
Pressurant Bottle	-40 to 150	-27 to 107	---	-3 to 102	---	10 to 115	---
Recharge Bottle	-40 to 150	-18 to 126	---	7 to 119	---	24 to 134	---
Valve Panel	-320 to 120	-5 to 84	---	10 to 86	---	16 to 106	---

Temperature predictions include MIL-STD-1540B 20 °F uncertainty margin where applicable. Components with heaters do not include uncertainty margin on minimum temperature.

Command & Data Handling (C&DH) Subsystem - The C&DH provides for formatting and transmission of housekeeping and experiment data and the capability for the decoding and distribution of commands to operate the payload during the mission. The C&DH also provides for the transmission of data downlink and the acceptance of ground command uplink via standard Orbiter communication links that interface with the HH-M avionics unit. Off-the shelf hardware is utilized and contains elements that accomplish control and monitoring of the sensors, valves, and other components of the experiment subsystem. Control of the experiment sequencing functions is handled by the on-board computer (OBC). Communications between the C&DH and the other subsystems is via a multiplex data bus.

Experiment Electronics Subsystem - This subsystem contains the experiment valve electronics (EVE) unit which controls the application of power commands to heaters and valves in the experiment subsystem. It provides the interface between the C&DH and the components that have to be controlled in the experiment subsystem. Also all instrumentation requiring unique electronics for signal conditioning or power regulation have these units located in this subsystem.

The capability of the Hitchhiker/Shuttle small payload power system allows for 1.75 kw for up to 6 attached payloads. (attached to the Hitchhiker) If no other payloads will use the MPESS structure in conjunction with CONE, the full 1.75 kw is available. We will ask for approximately 1/3 of the 1.75 kw available.

Another constraint is the 12.5 kwh per day levied by the capabilities of the fuel cell. The average of 5.65 kwh/day used by CONE is well below the maximum.

5.4.2 Command and Data Handling

We have baselined the SCI μDACS C&DH Subsystem. It is 3441 cubic cm (210 cubic in) in volume, weighs 4.1 kg (9 lbs), uses 13-14 watts with a single processor. Each processor uses 2 to 4 watts. The functions performed are: data acquisition, telemetry output, communication protocols, command reception, command issuance, processing, and distributed system. The microprocessor used is an Intel/Harris 80C86/RH CPU. A 1750A CPU can be substituted. Three power modes are available: full operating, standby, and power strobed off. The first unit was qualified in the first quarter of 1991. Qual levels are 9.8 g rms and 20 g rms, and the unit is designed to 50 g rms. The first unit flies in the summer of 1992 on SPV for MIT, an SDIO experiment on an ELV. Fault tolerance includes triply redundant control lines, error detection and correction on the data bus and address bus, internally redundant Asynchronous Interface Controllers (ASICS), and dual triply redundant watchdog timers. A triple write key is provided for all system critical functions where the system requires writing the the correct address with correct data three times in succession. A block diagram of the μDACS as proposed for CONE is shown in Figure 5.4.2-1. A single string configuration is baselined.

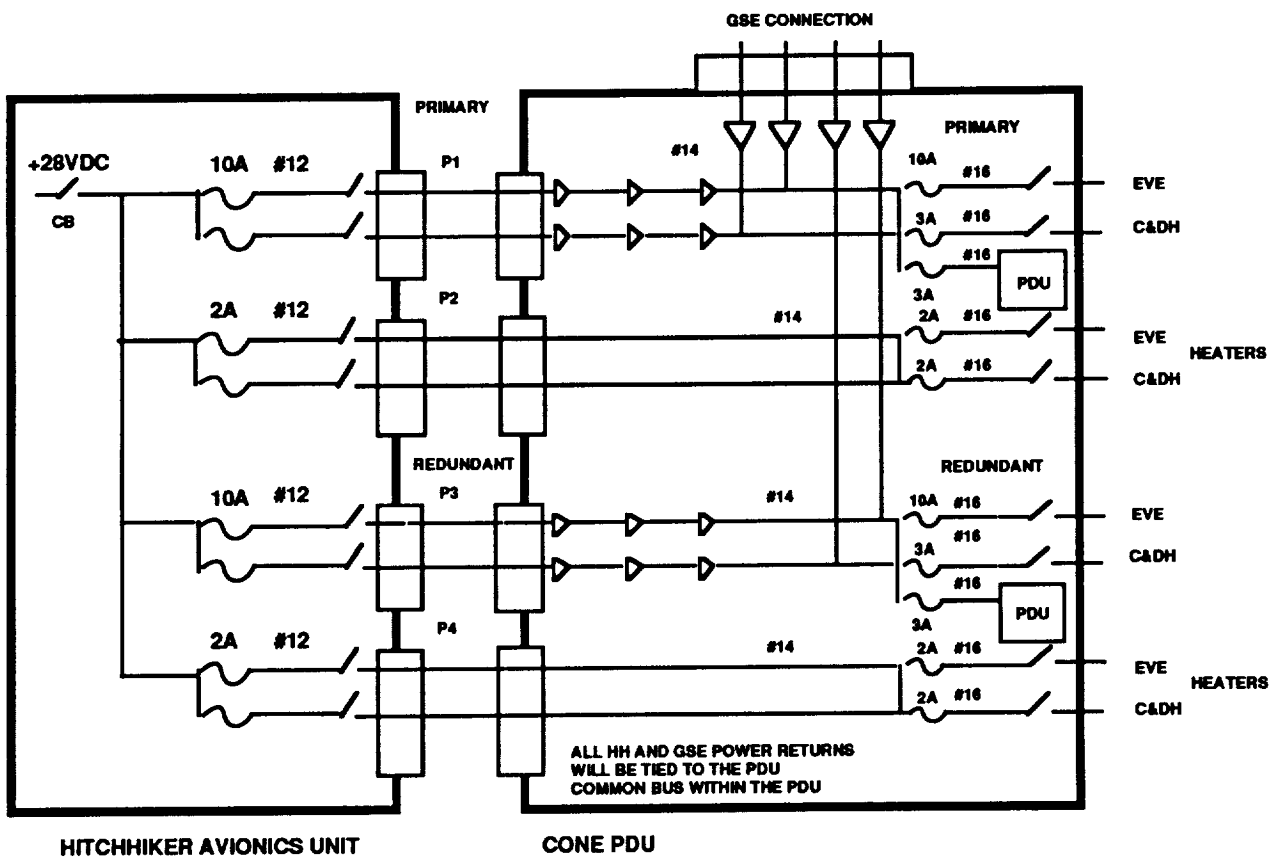

Figure 5.4.1-1 Power Distribution Schematic

The C&DH assembly contains a card that accepts the analog data from the experiment sensors, and then through various stages amplifies and converts the signal to digital. The data is then sent to the CPU to format the data for transmission to the OBC and/or the Hitchhiker. The cards in the assembly are listed with their functions in Table 5.4.2-1.

The OBC requirements are minimal. In doing a survey for memory selection, the CPU usage was very modest. The CPU contains 128K of RAM and 64K of PROM which is sufficient for CONE.

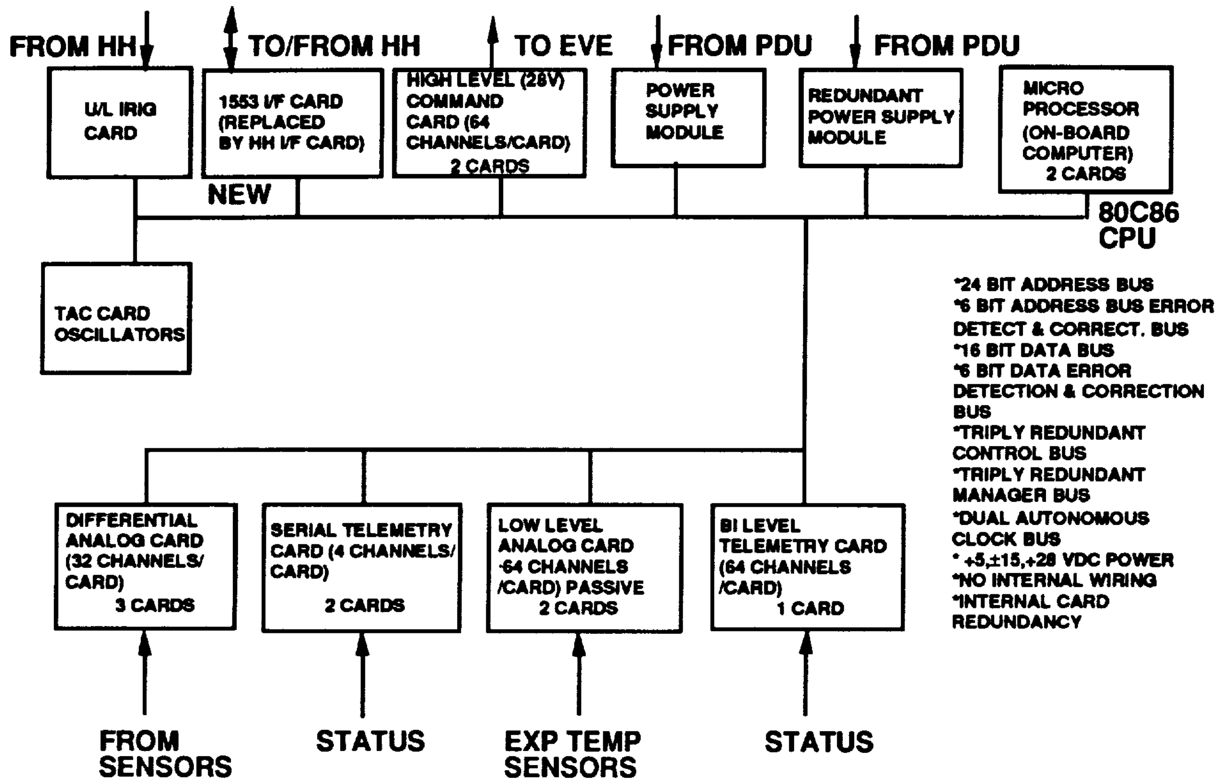

Figure 5.4.2-1 CONE C&DH Unit Block Diagram

Seven distinct events are controlled by the standard switch panel, not including the Hitchhiker-required power up events. The events having to do with the on board sequence interface directly to the OBC through the CONE C&DH Unit. The events opening or closing valves activate power relays to transfer valve power to the valve drivers.

The SSP contains both momentary and positive position switches that will be used to enable specific CONE functions. The first two switches are reserved for Carrier use (Carrier Avionics Unit power up). The remaining switches will be used for experiment start/stop and particular experiment valve positioning. SSP talkbacks will be used to show enabled switch/function positions.

Switch panel control is normally provided only to inhibit a hazardous function or provide a crew-controlled function which must be synchronized with some other crew activity such as Orbiter attitude control. The use of the SSP is determined by NASA based on STS manifesting rules. Coil resistance for the SSP mechanical indicator is 28 ± 3k ohms. On = Gray = 18 to 32 vdc. OFF=Stripes=0 to 5 VDC. The maximum current through a SSP switch is 1 amp (dc only). The maximum current required to drive an indicator is 30 ma. There are 10 switches available for those payloads using the Standard Mixed Cable Harness (SMCH).

Table 5.4.2.1-2 CONE Support Subsystems Measurement List

<u>EPS</u>
Main Bus Voltage (0-36 vdc)
Total Load Current (0-24 amps)
DC Bus Undervoltage Sensor Enable/Trip
Bilevel Word 1
Bilevel Word 2
PDU Temperature
PDU, EVE, C&DH Heater Status
Heater Command Status

<u>C&DHS</u>
C&DH Unit Status
Remote Interface Status
OBC Monitor (Counter bits in 20 millisec increments)
Safe/Hold Mode Enable Output & Return
OBC Dump

<u>EVE</u>
EVE Power Status
Valve Drive Amplifier Power On/Off
(Each Valve Status)
Experiment Heater Status
Status of Experiment Heater Commands

5.4.2.2 Commands

Upon reception of a complete command uplinked, the C&DH will validate the command and act accordingly based on the control byte. The command packet number will send down in the telemetry frame byte when it has been accepted. If the command has is not acceptable, the telemetry byte " command reject count" will be incremented and the "command reject status" byte will contain a status code indicating the reason. The updated sequence must begin with a command packet number greater than already processed.

A flag in the control byte will indicate that the command is to be executed upon reception. The C&DH will transmit the command to the appropriate subsystem component and follow it up with the triggers indicated in the command data field. If the flag indicates the command is to be stored for later execution, the C&DH will store the command information and the control byte in a queue. The command at the top of the queue is downlinked in the next telemetry frame.

Approximately 72 commands for CONE are required (Doubled to reverse the command action - ie, on and off). The serial digital command capability and/or the discrete command capability can easily handle the required commands. Commands can be issued from the ground or the computer. The crew has the capability to command functions from the standard switch panel. These commands involve sequence operation or valve commands. The command total can be either discretes or serial. Inputs for the valve drivers should be serial. The quantity of commands is shown in Table 5.4.2.2-1 to determine the number of on/off events required. OBC internal controls are not included in this total.

Table 5.4.2.1-1 CONE Experiment Measurements

INSTRUMENT ID	RANGE	SAMPLE RATE	NUMBER SENSORS	LOCATION	ACCURACY (±)
TEMPERATURE (°R)					
VACUUM JACKET	400-600	B	3	SUPPLY	1.0
MLI INSULATION	120-600	B	3	SUPPLY	2.0
FOAM INSULATION	120-600	B	3	SUPPLY	2.0
TANK WALL	120-170, 120-600	A	5	SUPPLY	0.5, 2.0
TANK FLUID	120-170, 120-600	A	5	SUPPLY	0.2, 2.0
LAD FLUID	120-170	A	3	SUPPLY	0.2
SUPRT/PENTR/OUTLET	120-600	B	7	SUPPLY	2.0
TVS FLUID/HX/FM	120-170, 120-600	B	4	SUPPLY	0.2, 2.0
VENT FLUID	120-600	B	3	OTHER	2.0
STORED PRESSURANT	400-600	B	1	OTHER	1.0
OUTFLOW LINE FLUID	120-170, 120-600	A	3	OTHER	0.2, 2.0
COMPACT HEAT EXCHANGER/FM	120-170	B	5	SUPPLY	0.2
MIXER PUMP	120-170	A	1	SUPPLY	0.2
RECHARGE BOTTLE	120-600	A	3	OTHER	2.0
OUTFLOW HEAT EXCHANGER	120-170, 120-600	A	4	OTHER	0.2, 2.0
PRESSURANT DIFFUSER	120-600	A	1	SUPPLY	2.0
PRESSURE (PSIA)					
TANK	10-20, 15-30, 0-50	A	3	SUPPLY	0.05,0.1, 0.5
TVS	0-50	B	1	SUPPLY	0.5
VENT FLUID	0-50	B	1	OTHER	0.5
STORED PRESSURANT	0-2000	B	1	OTHER	20
RECHARGE PRESSURANT	0-4000	B	2	OTHER	40
OUTFLOW LINE FLUID	0-50	A	2	OTHER	0.5
COMPACT HEAT EXCHANGER	0-50	B	1	SUPPLY	0.5
LOW FLOW CONTROL ORIFICE	0-10 PSID	A	1	OTHER	0.1
REGULATED PRESSURANT	0-50	A	1	OTHER	0.5
FLOWRATE (LB/HR)					
TRANSFER LINE FLUID	0-2000	A	1	OTHER	20 LB/HR
TVS	0-0.5	B	1	SUPPLY	0.005 LB/HR
COMPACT HEAT EXCHANGER	0-10	B	1	SUPPLY	0.1 LB/HR
QUANTITY GAUGING					
TANK FILL VOLUME	0-100%	A	1	SUPPLY	0.2 IN
LIQ/VAPOR POS DETECTOR	WET/DRY	A	5	SUPPLY	0.2 IN
ACCELERATION*					
3-AXIS ACCELERATION	1-500 μG	C	3	CARRIER	5.0 μG
PUMP POWER					
MIXER	0-5 W	B	1	PUMP PWR SOURCE	0.05 W
HEATER POWER					
SUPPLY TANK HEATERS	0-40W	B	4 ELMTS	HTR PWR SOURCE	TBD
TVS/CHX FLOW METER HEATERS	0-100W	B	2 ELMTS	HTR PWR SOURCE	5.0 W
STATUS					
VALVE POS	OP/CLOSE	A	8	SUPPLY	N/A
VALVE POS	OP/CLOSE	A	9	OTHER	N/A

NOTE: SAMPLE RATES ARE CLASSIFIED AS FOLLOWS:
1 SAMPLE PER SEC = A
1 SAMPLE PER 10 SEC = B
* 100 SAMPLE PER SEC = C (ACCELERATION TO BE PROVIDED BY AN EXTERNAL SAMS PACKAGE)

Table 5.4.2-1 Logic Cards in the C&DH

MICRODACS LOGIC CARD	FUNCTION	FUNCTION
•ANALOG SIGNAL PROCESSING	-FILTER -2ND STAGE GAIN -MUX	-PROGRAMMABLE SETTLING TIME
-1ST GAIN STAGE	-AUTO ERROR VOLTAGE NULLING	-PROGRAMMABLE OFFSET VOLTAGES
-COMMON MODE VOLTAGE SENSE	-DIGITAL SIGNAL PROCESSOR FILTERING, FOURIER TRANSFORMS	-TRACK AND HOLD CIRCUIT
•FMDM INTERFACE	-THE SLAVE SIDE OF THE STS FMDM	-INTERFACE PROVIDES THE SHUTTLE GPC WITH 40 MEASUREMENTS
•PO-28 -RISE AND FALL TIMES ARE PRESETABLE & LOAD INDEPENDENT	-PROVIDES SHAPED 28 VOLT PULSED OUTPUTS FOR UP TO 96 INDUCTIVE LOADS	-PULSE WIDTH IS ADJUSTABLE UNDER SOFTWARE CONTROL
•CLOCK DISTRIBUTION	-RECEPTION AND DISTRIBUTION FROM EXTERNAL CLOCK SOURCE	
•DISCRETE I/O	-PROVIDES UP TO 80 SIGNALS TO CONTROL/MONITOR EXTERNAL APPARATUS	-PROVIDES SELECTABLE VOLTAGE THRESHOLDS
•SDIO I/F	-PROVIDES CPU OUTPUT MEDIUM	
•TELEMETRY INTERLEAVER	-GETS DATA FROM EITHER I/O SOURCES OR MEMORY (PROM FORMAT)	
-FOUR FORMATS AVAILABLE PLUS A TEST FORMAT	-PROGRAMMABLE BIT RATES UP TO 1 MBIT	-ADDRESSES, COLLECTS, AND INTERLEAVES PCM DATA
•PRECISION CURRENT CARD -1 TO 10 MILLIAMPS OF CURRENT MUXED TO UP TO 64 OUTPUTS -OUTPUT UNDER S/W CONTROL	-PROVIDES MULTIPLEXED, STROBE, TRANSDUCER EXCITATION SOURCES FOR USE WITH THE 4-WIRE RTD TEMPERATURE SENSORS.	-MEMORY MAPPED TO THE SAME LOCATIONS AS THE ANALOG SIGNAL PROCESSOR
•I/V CONVERTER CARD	-TRANSFORMS LOW LEVEL CURRENTS TO A PRECISION VOLTAGE	-64 INPUTS (ZERO IMPEDANCE)

The position of the switch wiper corresponds to the position of the switch bat handle. Moving the handle up moves the wiper up (left). A switch with a triangle indicates momentary. Most of the switches are maintained. To use them as momentary switches they must be repositioned after use. Figure 5.4.2-2 shows the Standard Switch Panel with CONE markings to indicate those functions that require crew intervention.

5.4.2.1 Measurements

The list in Table 5.4.2.1-1 contains those primary and secondary measurements required to successfully conduct the CONE categories of demonstrations experiments which are defined by the enclosed experiment data base and instrumentation necessary to obtain the required experimental data for an understanding of the associated processes, as well as for the verification and correlation of analytical predictions.

The instrumentation for the CONE experiment subsystem consists of those sensors, status and position indication devices required to insure the safety of the operation of the experiment subsystem, provide data and control capability necessary to conduct the experimental tests and provide data for experiment analyses.

These devices will interface with an existing C&DH system with either an 8 or 12 bit capability. Required ranges and accuracies were developed assuming an 8-bit system.

For the most part, no attempt has been made to duplicate transducers at a single location for redundancy purposes. Similar sensors are installed in close proximity to each other and are of

Table 5.4.2.1-2 CONE Support Subsystems Measurement List

EPS
Main Bus Voltage (0-36 vdc)
Total Load Current (0-24 amps)
DC Bus Undervoltage Sensor Enable/Trip
Bilevel Word 1
Bilevel Word 2
PDU Temperature
PDU, EVE, C&DH Heater Status
Heater Command Status

C&DHS
C&DH Unit Status
Remote Interface Status
OBC Monitor (Counter bits in 20 millisec increments)
Safe/Hold Mode Enable Output & Return
OBC Dump

EVE
EVE Power Status
Valve Drive Amplifier Power On/Off
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Status of Experiment Heater Commands

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experiment electronics. The sequence of testing will not only verify operation of the C&DH Assembly, but will also help in assuring that the power interface, data interface and sequence of commands are correct. The OBC processor control functions also can be checked.

Each of the avionics boxes will go through a series of tests and analyses prior to acceptance. As each of the parts of the avionics are added to the C&DH unit, that part of the simulation will be taken off line.

Because the Hitchhiker Avionics Unit is not available to the project until integration at GSFC, the simulation is required through delivery of CONE to GSFC. Even with all of the components, a mission sequence will still require inputs and outputs from the simulation.

5.4.3 On-Board Computer and Software

The CONE processor (OBC) functional capabilities include:

- Control pressurizing and depressurizing
- Handle set/preset of valves
- Process interrupts
- Handle time
- Process limit comparisons
- Handle heater controls and instrument on/off
- Control Logic Processing
- Control Algorithms
- Permit start/stop of the functional sequence and restart where left off

The CONE C&DH processors functional capabilities include:

- Forward data to the GPC
- Handle sensor processing
- Process uplink commands
- Format downlink data

The software for CONE is first divided into flight and ground activity. Each of these activities are then further subdivided as shown in Figure 5.4.3-1.

The command processor provides system initialization, command decoding, and process selection. The Inflight Processor controls scheduling and descheduling tasks, processes uplink commands, and processes mission sequence changes. The Preflight Control Processor controls tasks pertaining to preflight testing and verification. Common Control Processing controls functions that are common to both Preflight and Inflight processing. The Hardware Handler controls all hardware/software interfaces for the CONE Flight System.

The flight software is designed to support the investigation of cryogenic system performance, process evaluations, and the obtainment of engineering data. The flight software is functionally grouped into experiment control and command and data management. Experiment control is concerned with command validation and execution, commanding of valves and heaters, and the execution of experimental processes.

An updateable on-board flight sequence will be stored in the on-board computer (OBC). The on-board computer, in conjunction with the rest of the command and data handling subsystem, will route commands to the function to be performed. Software functions can be terminated or temporarily suspended in order to wait for further inputs from the crew (Standard Switch Panel) or the ground (uplink).

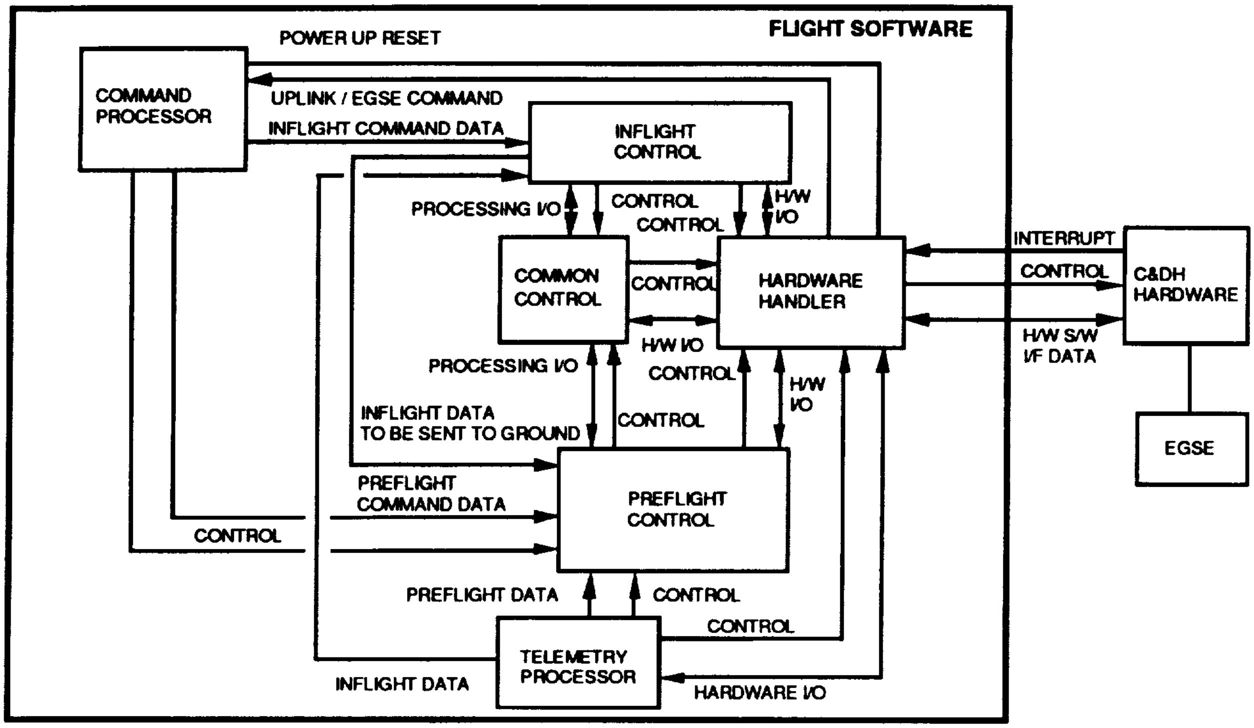


Figure 5.4.3-1 Flight Software Modules

All experiment set processes will be grouped in modules and executed upon command. Each process within a module is executed in sequence under control of the experiment sequence. During execution, the sequence controller will cycle through each experiment, maintain a status of the current executing process, and stop upon completion of module execution if required for crew intervention. Failure to complete a process within a designated time allocation will time-out the process and terminate its execution.

Software Sizing - An estimate of the software size of the flight and ground software was produced from a software architecture, sizing, and estimating tool which is a forward chaining rule-based expert system utilizing a hierarchically structured knowledge data base of normalized parameters to provide derived software sizing values by functionality, scheduling, and associated manloading outputs.

The flight software source lines of code (LOC) were estimated as:

•Systems -320 LOC
•Applications -12500 to 14000 LOC
•Support -3000 LOC

Total -15820 to 17320 LOC

The ground software source lines of code were estimated as

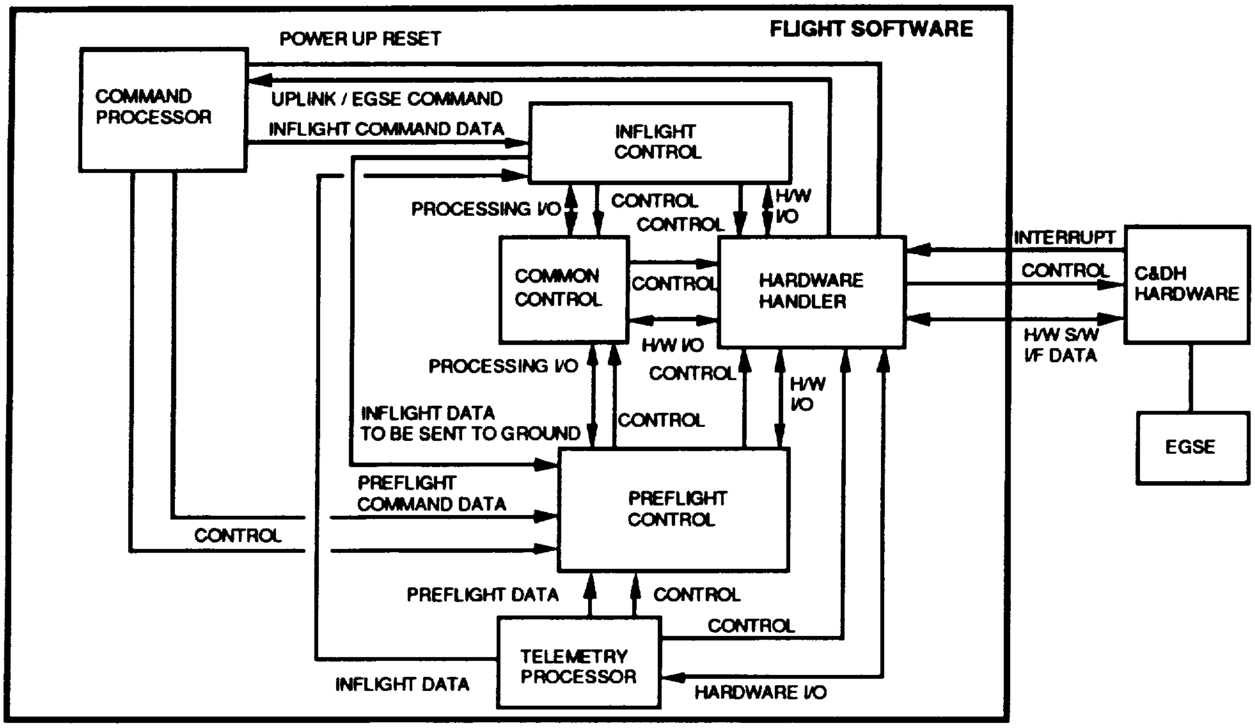
•Systems -2650 to 2800 LOC
•Applications -6350 to 7500 LOC
•Support -2100 LOC

Total -11100 to 12400 LOC with 1275 to 1300 data statements

Table 5.4.2.1-3 CONE Telemetry Frame

HEX ADDRESS	DESCRIPTION	BYTE
000	SYNC	l(hex) a(hex)
001	SYNC	c(hex) f(hex)
002	SYNC	f(hex) c(hex)
003	SYNC	l(hex) d(hex)
004	FRAME COUNT	msb..........lsb
005	MET	dddd dddd
006	MET	hhhh hhhh
007	MET	mmmm mmmm
008	MET	ssss ssss
009	ACT CNTS	msb—ms byte—lsb
00a	ACT CNTS	msb—ls byte—lsb
00b	FLAGS	ssst hpdc
00c	LAST CMD PKT ACC	msb————lsb
00d	CMD REJCT CNTRL	msb————lsb
00e	CMD REJECT STATUS	———tbd———
00f	NEXT CMD OUT ADD 0	byte 0
...		
037	LAST CONE CMD RCVD	byte 1
...		
040	LAST CMD EXECUTED	byte 2
...	COMPONENT 0	
050	SYS CONTROL CHANNEL	b7————b0
...		
060	HTR CONTROL CHANNEL	b7————b0
...		
070	LEVEL DETECTOR CHANNEL	b7————b0
...		
080	VALVE DRIVER CHANNEL	b7————b0
...		
090	DC VALVE CHANNEL	b7————b0
...		
0a0	SENSOR MEASUREMENT CHANNEL	b7————b0
...		
0b0	PDU CHANNEL	b7————b0
...		
0c0	PARITY	xxxx xxxx
	BIT SUM (EXCLUDING PARITY AND SYNC)	xxxx xxxx

A transparent data system is available for payloads through the Hitchhiker Avionics Unit. The data communications interface generally remains unchanged from the payload viewpoint, independent of the location of the payload- at the payload contractors, at the integration facilities (GSFC and KSC) or during flight operations. The asynchronous uplink is used to transmit asynchronous command messages and MET messages to the payload. The interface operates at 1200 baud asynchronous data rate. Each signal contains one start bit, eight data bits (no parity), and one stop bit. The entire message, including sync and check bytes are transmitted to the payload port on the Hitchhiker avionics Unit. The format of the GSE message is identical to the flight message.



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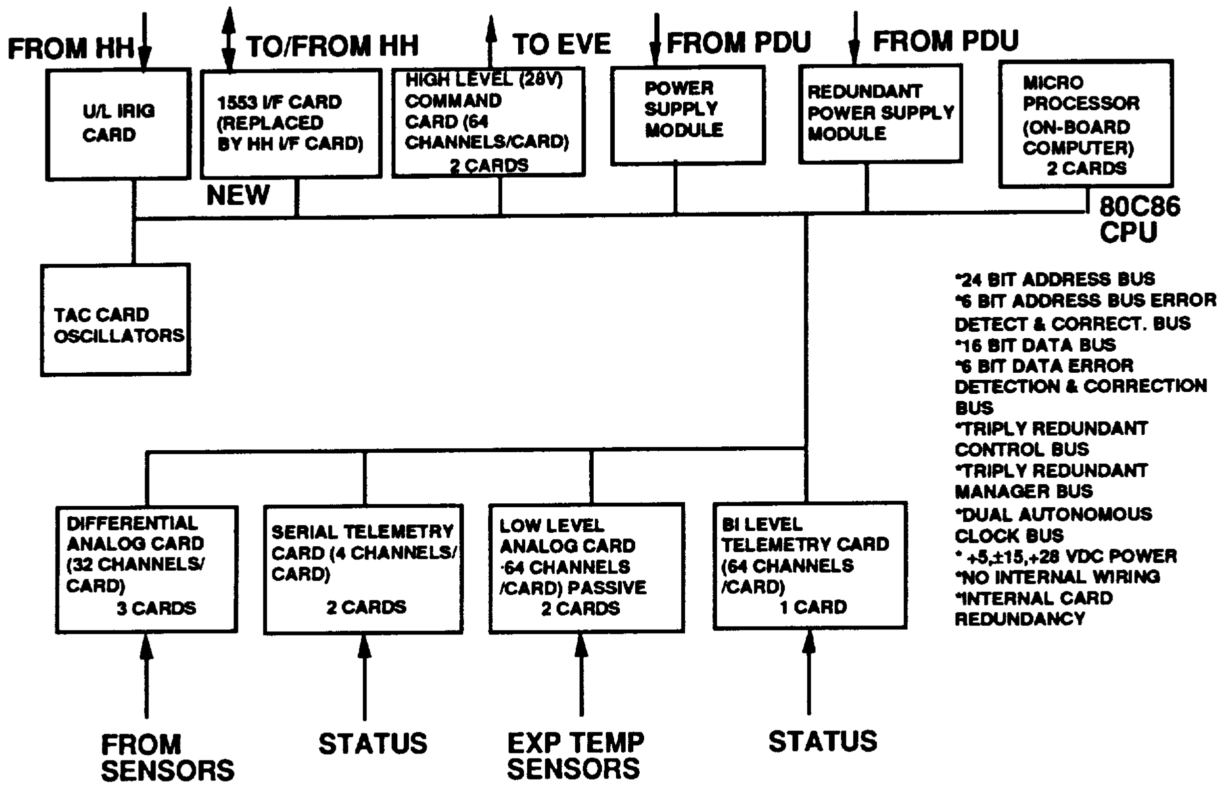

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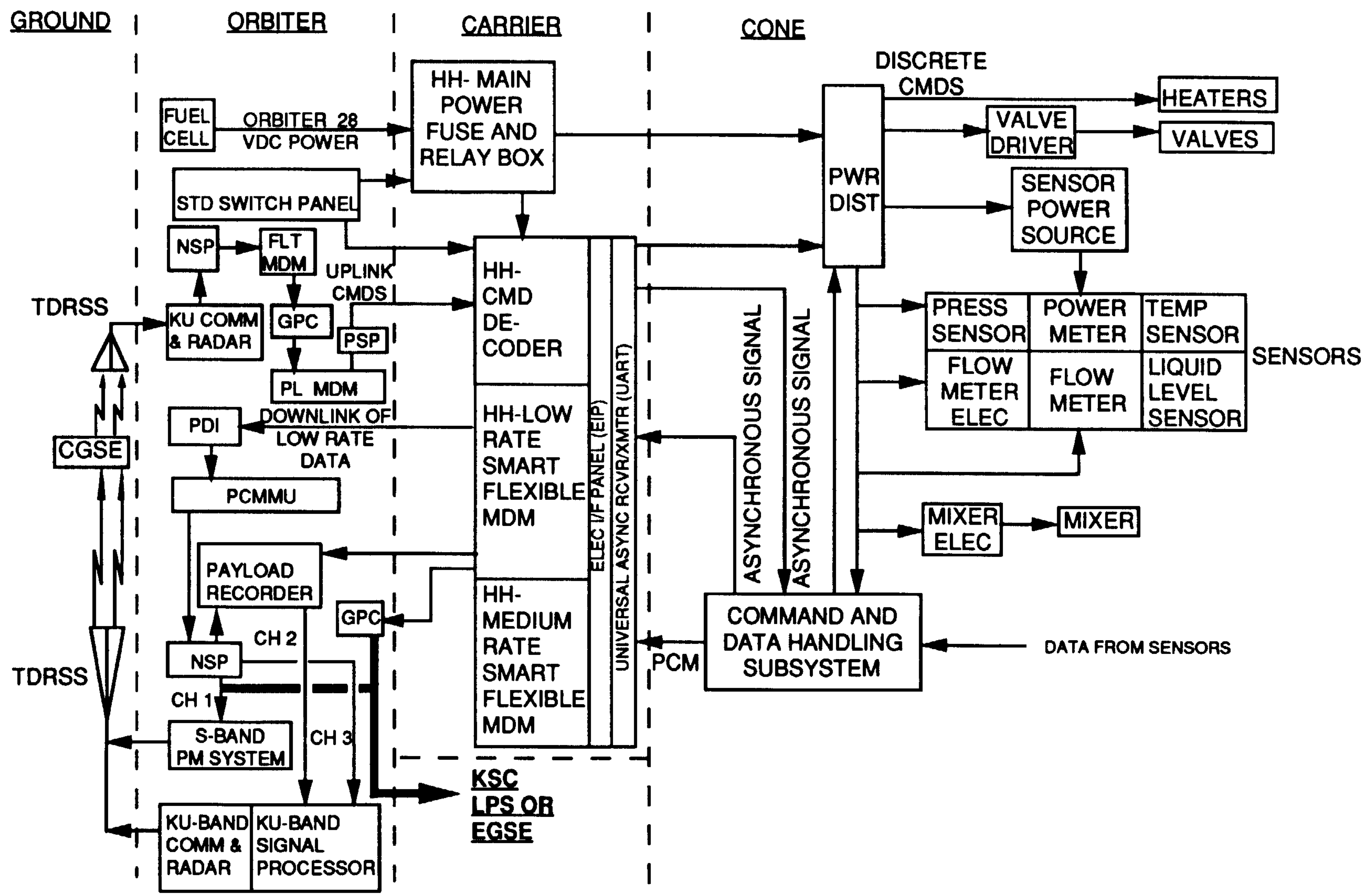

Figure 5.4-1 CONE Avionics Block Diagram

Experiment Valve Electronics (EVE) unit. Relays in the Power Distribution Unit will be used as drivers for valves and heaters and to switch bus power to the C&DH unit and the experiment electronics.

Table 5.3-2 CONE Thermal Analysis Results Summary

		0° Beta Angle		60° Beta Angle		90° Beta Angle	
	Flight Allowable °F	Temp. °F	Duty Cycle	Temp. °F	Duty Cycle	Temp.°F	Duty Cycle
Avionics Equipment							
C&DH	-11 to 142	8 to 115	---	14 to 117	---	16 to 141	---
EVE	32 to 124	39 to 95	77.2%	40 to 98	48.8%	40 to 119	38.0%
FME	-40 to 165	10 to 140	--	21 to 145	---	26 to 171	---
PDU	32 to 124	40 to 107	77.5%	40 to 107	40.4%	40 to 133	24.0%
Cryogenic Storage Components							
LN2	-320 Nominal	Temp	Held	Constant	as	Boundary	Node
GN2	-320 to 120	-8 to 79	---	13 to 83	---	20 to 107	---
LN2 Storage Tank	-100 to 150	-64 to 110	---	-29 to 101	---	-9 to 116	---
Pressurant Bottle	-40 to 150	-27 to 107	---	-3 to 102	---	10 to 115	---
Recharge Bottle	-40 to 150	-18 to 126	---	7 to 119	---	24 to 134	---
Valve Panel	-320 to 120	-5 to 84	---	10 to 86	---	16 to 106	---

Temperature predictions include MIL-STD-1540B 20 °F uncertainty margin where applicable. Components with heaters do not include uncertainty margin on minimum temperature.

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Experiment Electronics Subsystem - This subsystem contains the experiment valve electronics (EVE) unit which controls the application of power commands to heaters and valves in the experiment subsystem. It provides the interface between the C&DH and the components that have to be controlled in the experiment subsystem. Also all instrumentation requiring unique electronics for signal conditioning or power regulation have these units located in this subsystem.

reflective films, such as aluminized mylar. MLI is a more preferable thermal design if the component can tolerate the hot case. Exposed components respond more to environmental changes, and the resulting expected temperature range is greater. The EVE (Experiment Valve Electronics) is the highest heat dissipating component, and must be radiatively cooled. Its thermal design includes a white painted surface.

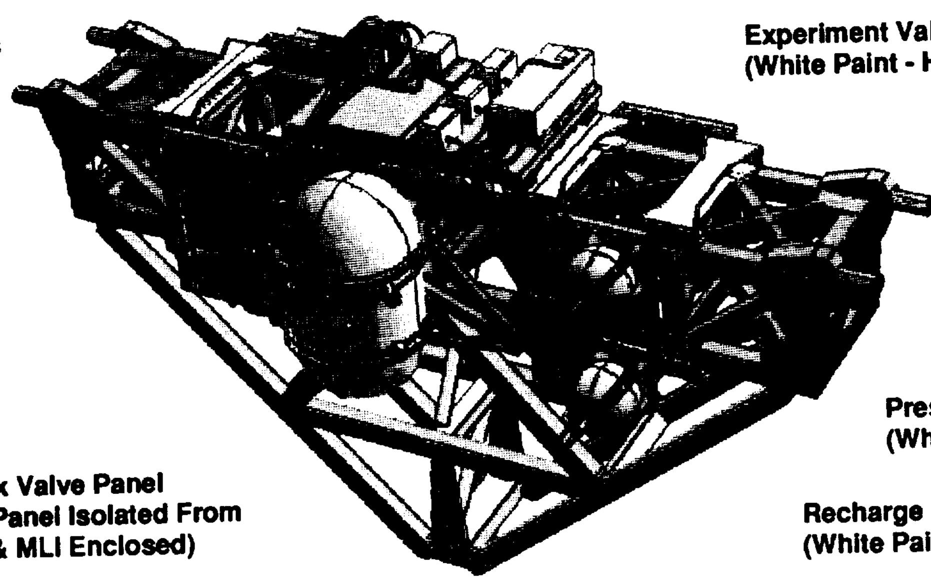

Figure 5.3-1 External Thermal Control System Design

It is desirable to isolate the cryogenic components from the environment. For this reason, MLI is used to insulate the valve panel assemblies. An exception to desired insulation is the recharge bottle. One of the thermal design objectives is to allow for a rapid warm-up of the recharge bottle during fill. Therefore, the recharge bottle is painted white to take advantage of its highly emissive property. For simplicity, the pressurant bottle was also painted white. It's allowable temperature range is not exceeded. Although, if desired, the option of insulating the pressurant bottle with MLI is still reserved. The storage tank already has a highly insulating vacuum jacket, so its outer case is painted white. Painted surfaces are preferred where acceptable because they are the least expensive and most easily applied.

The presented thermal control design is preliminary. There is flexibility existing in the design so that future modifications and design objectives can be addressed. At this stage, it is only intended that a feasible and satisfactory thermal control design be proposed.

The Command Processor is composed of a system initializer, a command decoder, and a process selector. After a power-up interrupt has occurred, all housekeeping and system initialization is accomplished. Control is then passed to the command decoder which handles all commands. The process selector is then passed control to schedule either the Inflight Processor or the Preflight Control Processor. Preflight will be selected if Mission Time is negative, otherwise Inflight will take control as the Mission Time has started indicating launch time.

The Common Control Processor is the embodiment of all flight processes that are common to inflight and preflight functions. A representative list of those functions are:

- Mission Sequence Controller
- Mission abort Controller
- Normal Termination Sequence Controller
- Storage Tank Dump Sequence Controller

The flight software processing is controlled by an OBC, a standard switch panel, and mission operations ground personnel.

The Hardware Handler is responsible for all software/hardware interfaces. It is comprised of several tasks each of which is assigned to a hardware device for handling all of its command control and output processing. A limit check function certifies measurement validity and reports detected hardware failures. A buffer handler maintains the circular buffers used for hardware input and output processing.

The Inflight Processor coordinates the various mission tasks by scheduling the appropriate automatic sequence modules which govern those tasks. Manual control for opening specific valves can be accomplished using the crew Standard Switch Panel.

The Preflight Control Processor coordinates the exercise of all preflight functions of the flight hardware and software systems. These include unit hardware verification and subsystem hardware verification. Validated C&DH functions are the interrupt system, real-time clock, interval timer, memory control. Functional checks are made for the OBC, valves, sensors, data for the GPC, and power recovery. Abort sequences are also performed. Inflight processing functions can also be invoked by the preflight processor to permit validation of the storage tank prior to launch. In addition, the Preflight Control can induce the Flight Software to run through a complete mission simulation via the Auto/Unit Inflight Control. This includes canned data sent to EGSE via the Hardware Handler.

Telemetry processing is accomplished using input multiplexers in the C&DH assembly. Analog signal processors take the multiplexer output and transfer the data to analog to digital converters. Passive analog control and differential analog control logic then provide an output to the network buses.

Discretes are processed through an attenuator network, through a multiplexer and then to threshold comparators before control circuitry outputs the signals to the network buses.

5.4.4 Experiment Electronics

The Experiment Valve Electronics Assembly is an offshoot from the Propulsion Module Electronics (PME), the valve and heater electronics for the NASA Standard Multimission Spacecraft (MMS). A similar package was developed for COLD-SAT. Circuit boards in the PME, not required for CONE, will be removed. This will require a requalification of the remaining hardware which includes the heater drivers, bilevel signal conditioning, serial digital telemetry logic, active and passive temperature signal conditioning, pressure sensor signal conditioning, serial digital command logic, and the valve drivers. A functional block diagram of the EVE is shown in Figure 5.4.4-1. Items shown by a crosshatch are components controlled by the EVE but not contained within the EVE.

be suitable unless the flight manifest can accommodate CONE requirements. Certain Orbiter attitudes are necessary to accomplish experiment and demonstration objectives while at other times any attitude is acceptable. Attitude coordination will be an integration requirement that will be worked in Phase C/D as a part of manifesting and mission integration.

Table 6.1-1 Requirements on Mission Segments

SHUTTLE

LAUNCH
ORBIT
PAYLOAD BAY DOORS OPEN
ATTITUDE CHANGE
RCS THRUSTER FIRINGS
CREW CONTROL [SSP]
PROVIDE PAYLOAD POWER
UPLINK OF GROUND COMMANDS
UPLINK OF SEQUENCE AND TIMING CHANGES
DOWNLINK OF PAYLOAD DATA
LANDING

HITCHHIKER MPESS

TRANSFER TIME
TRANSFER DATA
TRANSFER POWER
STRUCTURAL SUPPORT
SUPPORT PLATES

POCC

PROCESS DOWNLINK
PREPARE UPLINK
ANALYZE DOWNLINK DATA
PREPARE TAPES FOR SCIENTISTS

LERC

MANAGE PROGRAM
DEFINE GFP
COORDINATE INTERCENTER ACTIVITY
DEFINE EXPERIMENT

KSC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INTEGRATE PAYLOAD
INSTALL PAYLOAD IN SHUTTLE
END-TO-END TESTING OF PAYLOAD

GSFC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INSTALL PAYLOAD ON MPESS TOP
SYSTEM TEST PAYLOAD
SHIP PAYLOAD TO KSC
TRAIN POCC CREW

JSC

RECEIVE AND TRANSMIT COMMANDS
RECEIVE AND TRANSMIT TELEMETRY
TRAIN CREW

The drag requirement will allow JSC to select the orientation best suited to all the payloads. Long duration (6-8 hr) stratification testing requiring drag for minimal perturbations take place during sleep period so that they have a minimal impact on other payloads and the mission in general. Restrictions on on Orbiter orientation and other payload requirements could degrade the desired results of these tests. Rerunning tests could not be done due to the time available on the mission and the close sequencing of events. Certain operational holds are available for coordination of other mission events and crew availability. They are short time periods and do not allow for resequencing of activities.

Other perturbations will cause forces to be exerted on the LN2 Tank. The demonstration aspect of this mission provides the rationale for accepting the results obtained with unspecified forces for a large portion of the mission.

Other constraints include use of the Shuttle video and lighting systems. The location of the cameras may preclude use due to other payloads being in the way. A requirement may be imposed by CONE

6.0 MISSION DESIGN

6.1 Mission Requirements

The CONE on-orbit mission was developed so that the experiments and demonstrations could be accomplished on a nominal seven day Orbiter mission. A mission timeline was assembled to accommodate all of the tests within this time constraint while allowing for periods of system operations holds to provide for coordination with the crew and other operations that may impact the flow of desired CONE operations. Tests are arranged into six groups with the first three occurring at the high fill level for LN2 in the storage tank and the last three at a lower level resulting from the first expulsion (supply test). Active pressure control (APC) assessments comprise the majority of the mission events. The ordering of events had to accommodate crew availability to support orbiter operations for attitude and thruster firings for fluid positioning/settling. Two stratification tests desire periods of fluid quiescence and settling using Orbiter drag to orient LN2 in the storage tank. These operations are best accomplished during crew sleep periods and do not require crew involvement. All LN2 and GN2 will be depleted and expelled to space during a nominal mission; the system will return without concern for tank residuals.

The mission segments for CONE are defined as the NASA centers involved in CONE, the space shuttle, the Hitchhiker, and the POCC. These requirements, shown in Table 6.1-1, are levied on the respective organizations that provide services for payloads.

6.1.1 Shuttle and Hitchhiker Capabilities and Constraints

A carrier analysis was performed to select the most suitable carrier for the CONE mission. Mass and cg issues quickly eliminated Hitchhiker-G from consideration. Hitchhiker-M, an MPESS carrier, was selected because of the mass, volume and available services for Orbiter interfacing. A dedicated MPESS could also be used as the carrier but more complicated interfacing issues arise. GSFC provides this carrier and also provides integration and safety assistance to the user which was another big consideration for the HH-M selection.

Heater power is required on orbit after the doors are opened, but before the CONE payload is powered up, and after the CONE mission with the CONE payload powered down, but before the doors are closed. The use of the Hitchhiker POCC at GSFC and the standard POCC services provided are needed in this concept. The carrier flight services that are used by CONE are listed below. They all fall within the standard services and capabilities provided.

- HH-M
- Hitchhiker Avionics Unit
- 4 Ports (for supplementary heater power of 175 w)
- 236 w average power, 480 w peak, 5.65 kwhr/day
- Low rate data channel - asynchronous - 1 kbps
- Asynchronous command channel - 1 kbps
- 4 side attachment plates
- 2 top attachment plates

Assuming a vertical payload installation, the CONE payload will be installed with the storage tank on its side in the horizontal position. If the payload installation is horizontal, the tank will be in the vertical position. Either installation can be accommodated, but vertical processing has been baselined. Loading of GN2 and LN2 at the Pad is easily accomplished, with the manual loading valves quite accessible.

Two of the constraints levied by the Shuttle on the payload concern attitude and drag. Because the Orbiter can be placed in any attitude by the other payloads manifested with CONE, the attitude may not be suitable unless the flight manifest can accommodate CONE requirements. Certain Orbiter attitudes are necessary to accomplish experiment and demonstration objectives while at other times any attitude is acceptable. Attitude coordination will be an integration requirement that will be worked in Phase C/D as a part of manifesting and mission integration.

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DOWNLINK OF PAYLOAD DATA
LANDING

HITCHHIKER MPESS

TRANSFER TIME
TRANSFER DATA
TRANSFER POWER
STRUCTURAL SUPPORT
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POCC

PROCESS DOWNLINK
PREPARE UPLINK
ANALYZE DOWNLINK DATA
PREPARE TAPES FOR SCIENTISTS

LERC

MANAGE PROGRAM
DEFINE GFP
COORDINATE INTERCENTER ACTIVITY
DEFINE EXPERIMENT

KSC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INTEGRATE PAYLOAD
INSTALL PAYLOAD IN SHUTTLE
END-TO-END TESTING OF PAYLOAD

GSFC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INSTALL PAYLOAD ON MPESS TOP
SYSTEM TEST PAYLOAD
SHIP PAYLOAD TO KSC
TRAIN POCC CREW

JSC

RECEIVE AND TRANSMIT COMMANDS
RECEIVE AND TRANSMIT TELEMETRY
TRAIN CREW

The drag requirement will allow JSC to select the orientation best suited to all the payloads. Long duration (6-8 hr) stratification testing requiring drag for minimal perturbations take place during sleep period so that they have a minimal impact on other payloads and the mission in general. Restrictions on on Orbiter orientation and other payload requirements could degrade the desired results of these tests. Rerunning tests could not be done due to the time available on the mission and the close sequencing of events. Certain operational holds are available for coordination of other mission events and crew availability. They are short time periods and do not allow for resequencing of activities.

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Other constraints include use of the Shuttle video and lighting systems. The location of the cameras may preclude use due to other payloads being in the way. A requirement may be imposed by CONE

6.2 Mission Analysis

The mission design requires commanding the payload to run the experiment test set. An analysis was done to determine the best method to operate CONE. The results of this analysis are shown in Table 6.2-1. Activities performed by the flight crew and by the ground operations personnel are shown.

Table 6.2-1 Ground Activity vs Flight Activity during Mission

GROUND VS FLIGHT OPERATIONS ACTIVITIES

ON-BOARD SHUTTLE		AT POCC
•HITCHHIKER POWER ON	SSP	•SET HITCHHIKER POWER-UP RELAYS BY GROUND COMMAND
•HITCHHIKER CMD & DATA ON	SSP	•SET CONE PDU POWER-UP RELAYS BY GROUND COMMAND
•INITIATION OF EXPERIMENT TIMELINE SEQUENCE	SSP	•ANALYZE PAYLOAD DOWNLINK REALTIME DATA
•CHANGE SHUTTLE ATTITUDE		•CHANGE PAYLOAD SEQUENCE BY GROUND COMMAND UPLINK
•FIRE THRUSTERS		•CHANGE PAYLOAD SEQUENCE TIMING BY GROUND COMMAND UPLINK
•STOP TIMELINE SEQUENCE	SSP	
•INITIATE SAFE STATE	SSP	
•OPEN HIGH FLOW VENT (V6B)	SSP	
•RESTART OF TIMELINE SEQUENCE	SSP	
•OUTFLOW TEST START	SSP	
•OPEN TANK VENT VALVES (15A AND 16A)	SSP	
•OPEN TVS FLOW CONTROL VALVE (V14A)	SSP	

An analysis was performed to determine the steps required in a checkout prior to running the experiment sequences. Table 6.2-2 lists the checkout sequence necessary. The checkout cannot be run until at least 4 hours after the shuttle is on orbit.

Table 6.2-2 On-Orbit Checkout

TIME OF CHECKOUT
•SCHEDULED 4 HOURS AFTER LAUNCH
•TWO HOUR TIME BLOCK ALLOCATED FOR ANALYSIS OF DOWNLINK
TYPE OF CHECKOUT
•FUNCTIONAL DEMONSTRATION
•PROCESSOR MEMORY READOUT (MRO)
FUNCTIONAL DEMONSTRATION AND MRO SEQUENCE
•BEGIN DEMO •POWER UP CONE AND DOWNLINK TELEMETRY
•GROUND ANALYZES TELEMETRY DATA
•GROUND UPLINKS START OF CHECKOUT
•DOWNLINK MRO
•GROUND ANALYZES MRO
•CYCLE HEATERS
•GROUND ANALYZES HEATER WATT METER READINGS
•CYCLE VALVES (EXCEPT TANK VALVES THAT WOULD ALLOW LN2 FLOW) •SEQUENCE VALVES TO AVOID PRESSURIZING THE TANK
•GROUND ANALYZE VALVE POSITION STATUS AND THERMAL CONTROL SYSTEM
•END DEMO

The timeline for the mission is shown in Figure 6.2-1. Operations requiring crew participation are shown. These include shuttle maneuvering and reorientation and standard switch panel operations.

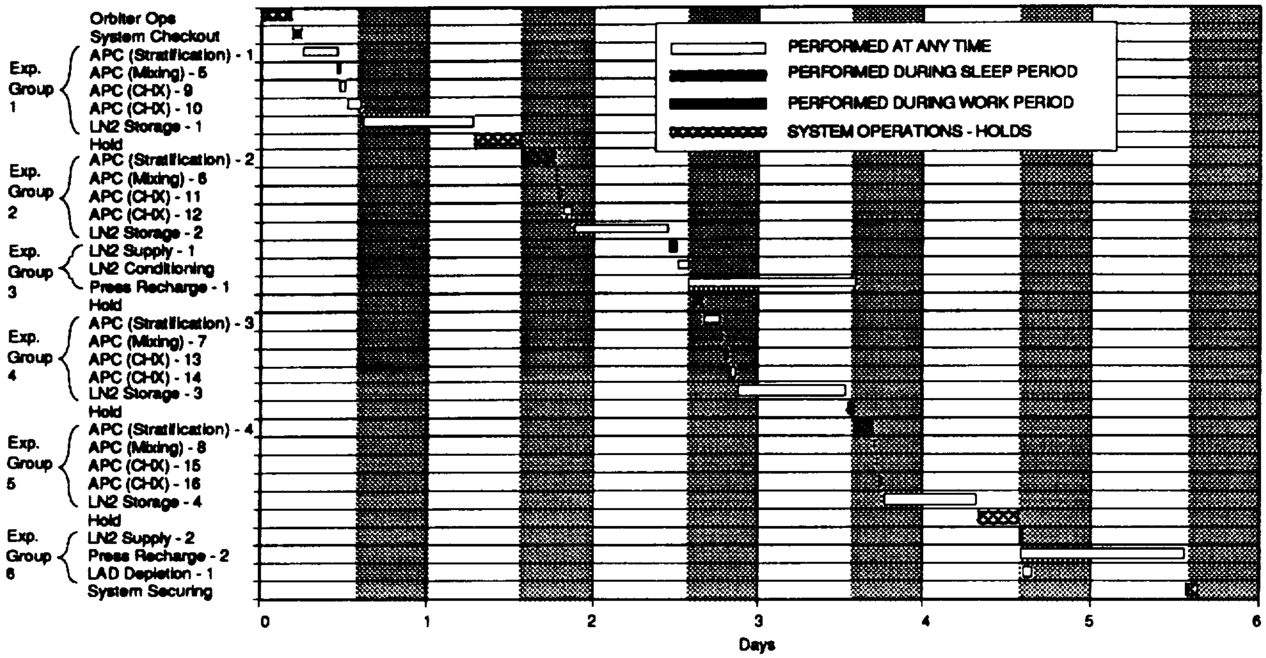


Figure 6.2-1 Mission Timeline

<u>LN2 Settling</u>

Liquid is propulsively settled three times during the mission. The settling was analyzed to determine the durations and Shuttle propellant quantities used. The assumptions used in the analysis were:

•A PRCS translations maneuver is used for settling.
•The Orbiter CG is midway between the forward and aft thrusters.
•The time for the liquid to fall to the end of the tank is determined by the equation $T = (2\Delta X/A)^{0.5}$.
•The settling time= 5 x time for the liquid to fall.
•I_{sp} = 3039 m/sec (310 lbf-sec/lbm)

The results are shown below in Table 6.2-3. The 172.6 kg (380 lbm) propellant used for settling is a conservative estimate. A more rigorous analysis would reduce the propellant quantity.

Table 6.2-3 LN2 Settling Requirements

Parameter	Cases		
Fill Level	80%	40%	10%
Height -cm (Inches)	40.6 (16)	60.9 (24)	101.6 (40)
Settling Duration (Sec)	12.5	15	20
Propellant -kg (lbm)	45.4 (100)	54.5 (120)	72.7 (160)

for a location with the capability to be viewed by a video camera. The location of the bulkhead TV cameras are: Xo=576 or 1307.

The attachment lens extreme camera centerlines are at stations

Xo	Yo	Zo
598	+71.5	446
598	-71.5	446
1285	+87.0	446
1285	-87.0	446

Which camera location that will be selected depends on the bay location of the payload. Keel cameras are also available but not required. Lighting will also be required close to the payload location in the bay.

The major CONE requirements that will affect the Shuttle are weight, volume and power. The requirement to settle LN2 requires the use of the primary RCS and ~380 pounds of propellant. The use of the Shuttle RCS will be negotiated with JSC. Manifesting the payload on a particular shuttle will be required prior to JSC determining what they will allow CONE to use.

Orbiter thermal constraints will determine the allowable time in the high drag mode. CONE required time will be to maintain the liquid orientation. No predetermined Shuttle attitude shown in JSC-07700 provides this required high drag attitude, but poses no unattainable requirement on the Orbiter.

LN2 in-bay venting will be negotiated with JSC as to allowable rates and amounts, as well required attitudes for the Orbiter when outflowing LN2 to space. Preliminary discussions with JSC safety indicate that the amount and velocity expected will be permissible.

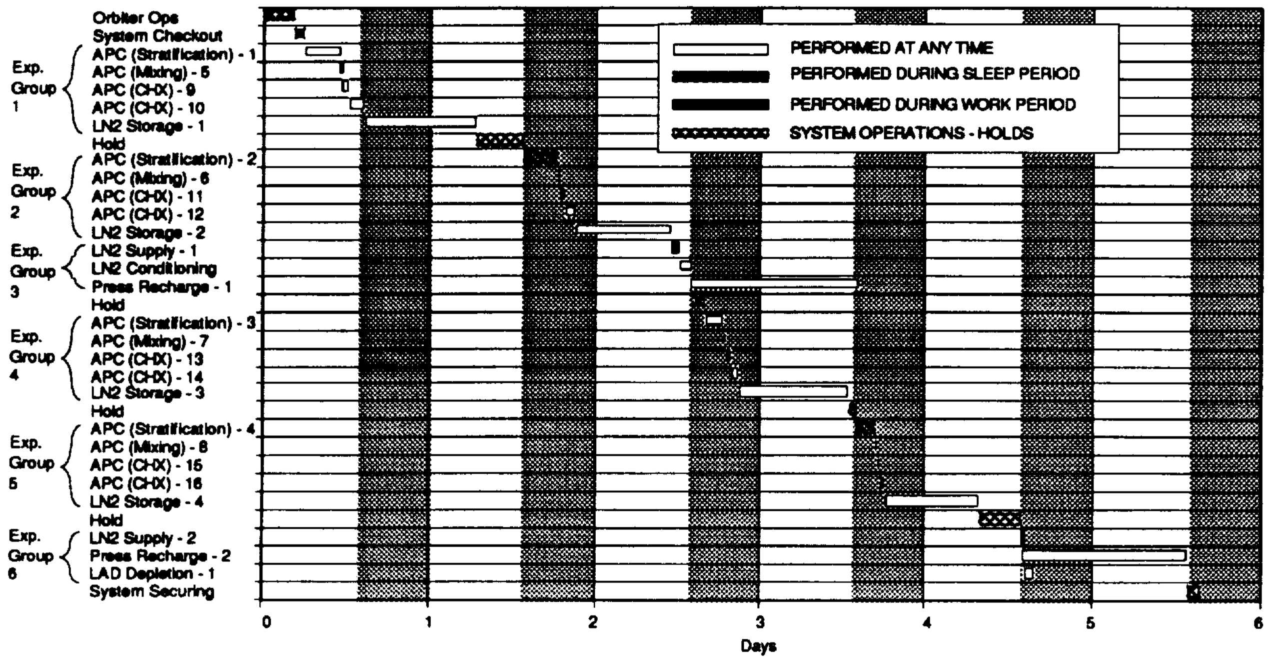
The Payload Integration Plan (PIP) is the agreement between the payload and JSC on the responsibilities and tasks which directly relate to the integration of the payload into the STS and includes identification of tasks that the NASA considers as standard and optional services.

The Launch Services Agreement (LSA) between LeRC and the Space Transportation System is signed after negotiations are completed in Phase C/D. Precedence is given to the LSA and then the PIP except for matters of safety where the "Safety Policy and Requirements for Payloads Using the STS", NSTS 1700.7 and "STS Payload Ground Safety Handbook", KHB 1700.7. Next in line are the Payload ICDs referenced in the PIP, then the PIP annexes that provide the details of the payload to JSC/KSC. LeRC is responsible (through its contractor) for the design, development, test, performance, and safety of the payload, GSE, as well as providing support to the NSTS analytical and physical integration activities identified in the PIP. The requirements in the PIP detail the CONE services provided by JSC/KSC are shown in Martin Marietta document MCR-91-1313.

Payload launch commit criteria are required for safety items only. Secondary payloads are not permitted mission success launch commit criteria. The launch commit criteria (LCC) for CONE to launch with an 85% full LN2 tank will become a desired mission success LCC which CONE will request.

The desire to set the payload launch configuration on the ground by providing power to the Hitchhiker before launch and then positioning switches on the Standard Switch Panel (SSP) onboard the Orbiter, will require negotiations with JSC/KSC. If this desire is not met, use of the T-0 umbilical will be required, which is an additional interface we wish to avoid.

The timeline for the mission is shown in Figure 6.2-1. Operations requiring crew participation are shown. These include shuttle maneuvering and reorientation and standard switch panel operations.



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7.0 GROUND SEGMENT DESIGN

The ground segment consists of the ground support equipment used for test and assembly and installation of the flight hardware and software along with the operations hardware and software at the Payload Operations Control Center. The operations concept limits the number of personnel thus sizing the POCC equipment. Figure 7.0.1-1 is a functional block diagram of the CONE GSE.

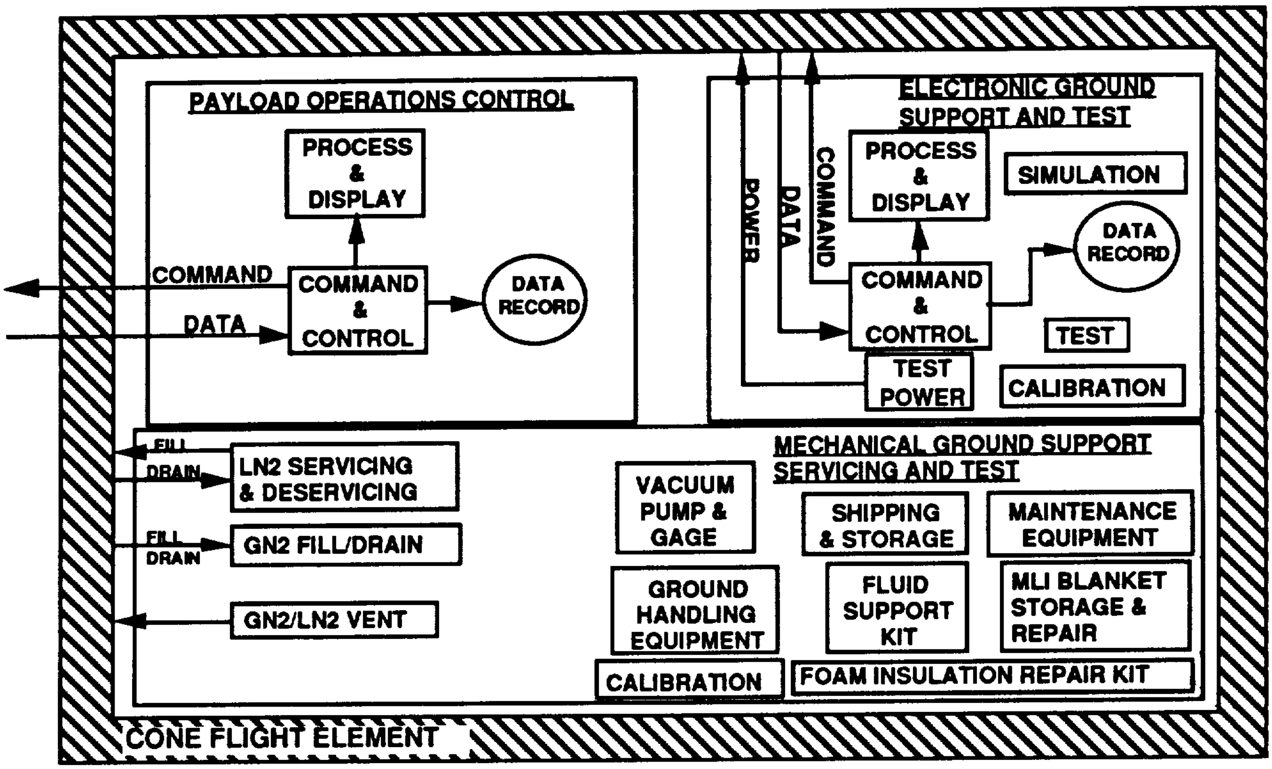

Figure 7.0.1-1 CONE Ground Segment Functional Block Diagram

Major Ground Segment Elements

Mechanical Ground Support Equipment (MGSE) - The MGSE provides ground servicing, handling support, transportation support, and maintenance functions for the payload. The major MGSE structural hardware items include a transporter with protective cover, handling and rotation dolly, handling/lifting slings , holding fixtures and installation tools. Alignment test equipment is provided. Support equipment for the experiment subsystem includes a LN2 servicing/deservicing system, high pressure GN2 experiment pressurant servicing panel, experiment subsystem leak check kits, fluid support equipment and miscellaneous calibration equipment.

Electrical Ground Support Equipment (EGSE) - The EGSE provides command, control, calibration, simulation, ground 28 Vdc power to the payload, and data management of the support and experiment subsystems during ground test and checkout operations. A major portion of the EGSE hardware is comprised of simulators, mission sequence and command generation system, monitoring system, display equipment and printer. In addition, a ground 28 vdc power supply, power subsystem support equipment, and electronics integration test equipment are provided. Ground S/W is included as part of this element.

Payload Operations Control Center (POCC) - The POCC provides in-flight command, control and management of flight data (both realtime and recorded) for CONE. Operations software is included in the POCC. The POCC includes a router, telemetry preprocessor, data management work stations, mission planning and scheduling work stations, and personal computers for experiment monitoring and data processing.

7.1 Mechanical Ground Support Equipment (MGSE)

MGSE provides for the following support, servicing and test functions:

- Provide handling capability for the flight element/subsystems.
- Provide for the shipping and transport of the integrated flight element.
- Provide for LN2 fill/drain for checkout, testing and prelaunch servicing of the storage tank.
- Accommodate GN2/LN2 venting for all LN2 fill/drain operations.
- Accommodate GN2 fill/drain for checkout, testing and prelaunch servicing of the pressurant bottles.
- Provide for mechanical support for sensor calibration.
- Support storage tank vacuum jacket pump down and gaging of vacuum levels.
- Protect, store and provide for the repair and maintenance of removable MLI blankets.
- Provide for the maintenance and repair of foam insulation on fluid lines, fittings and components.
- Provide for a miscellaneous fluid support kit containing flex hoses, fittings, gages, flow meters and other equipment needed to support the test and checkout processing of the CONE.
- Provide for the support mounting of the integrated flight configuration and the proper positioning of the system for ground test.

CONE System Support and Rotational GSE

The MGSE concept depicted in Figure 7.1-1 provides for a support, handling and rotational dolly for the experiment subsystem that supports various fabrication, assembly and test needs. Shipping is also accomplished with such a fixture. During the fabrication of the experiment subsystem elements it will provide for components support and test up to the completed valve panel and tank assembly level. Once the experiment subsystem elements are integrated together as shown, testing can be accomplished in both the vertical (landing configuration) and in the horizontal (launch configuration). The dolly is approximately 3.66 m (12 ft) long and 1.52 m (5 ft) in height. Rotation is accomplished by a motor drive mechanism. It can be transported to different areas in an enclosed truck. The rotating dolly structure simulates the HH-M structure from a mounting standpoint and can also accommodate the entire support subsystem.

Two GSE braces form a component of the dolly system that allows the 3 basic elements of the experiment subsystem to be handled as a unit once plumbing connections are made between the elements. Attachments are made to the brace using connections different from those that are required for flight mounting to the HH-M. Brace configuration does not interfere with the HH-M to experiment subsystem interface and allows the handling of the system as a unit. Once the integration to the HH-M is accomplished the GSE braces are removed. They are shown installed in Figure 7.1-1 but are not required to support the experiment subsystem to the dolly.

Mounting provisions at their respective flight orientations/locations are also provided on the dolly for the avionics subsystem and cabling harness. This dolly therefore provides a GSE structure that handles the integrated flight configuration and can support both ground test operations and shipping and handling of the flight hardware.

Experiment Subsystem GSE Brace and Handling Sling - The MGSE concept depicted in Figure 7.1-2 provides for handling and lifting for the experiment subsystem that supports various fabrication, Two LN2 storage tank overboard expulsions are planned. The first tank outflow will be used to establish a low level (40%) so that experiments at a depleted liquid level can be accomplished. During this outflow the first recharge bottle experiment is conducted. The second tank outflow will be used to assess the breakdown characteristics of the LAD and will expel most of the tank contents overboard. Approximately 1% residuals are expected. During this outflow the second recharge bottle experiment is conducted and includes a chilldown of the bottle prior to the liquid charge injection. Figure 6.2-2 shows the preferred Orbiter attitude for liquid outflow so that LN2 is directed away from the direction of motion of the Orbiter. This attitude is also used for the second and fourth stratification tests which take place during sleep periods where the best attainable quiescent periods may be obtained.

During the first outflow no restriction is placed on the Orbiter attitude. There may be attitudes that are more desirable if the relative position of the resulting LN2/GN2 vent cloud is a concern to the Orbiter. Approximately 120 lbs of LN2 is outflowed over a 70 min duration. The liquid exposed to the space environment will convert to approximately 6000 cu ft of GN2. Where the outflow occurs in the orbit is not critical

During the second outflow the Orbiter is placed into a high drag orientation to settle the tank liquid away from the LAD outlet for the entire outflow. Thrusters are also used for liquid position during the end of the outflow for the LAD depletion test. Approximately 120 lbs of LN2 is outflowed over a 15 min duration. The liquid exposed to the space environment will convert to approximately 6000 cu ft of GN2 in TBD min. Where the outflow occurs in the orbit is not critical.

A video record of both of these outflows is desired to visually investigate the outflow phenomenon.

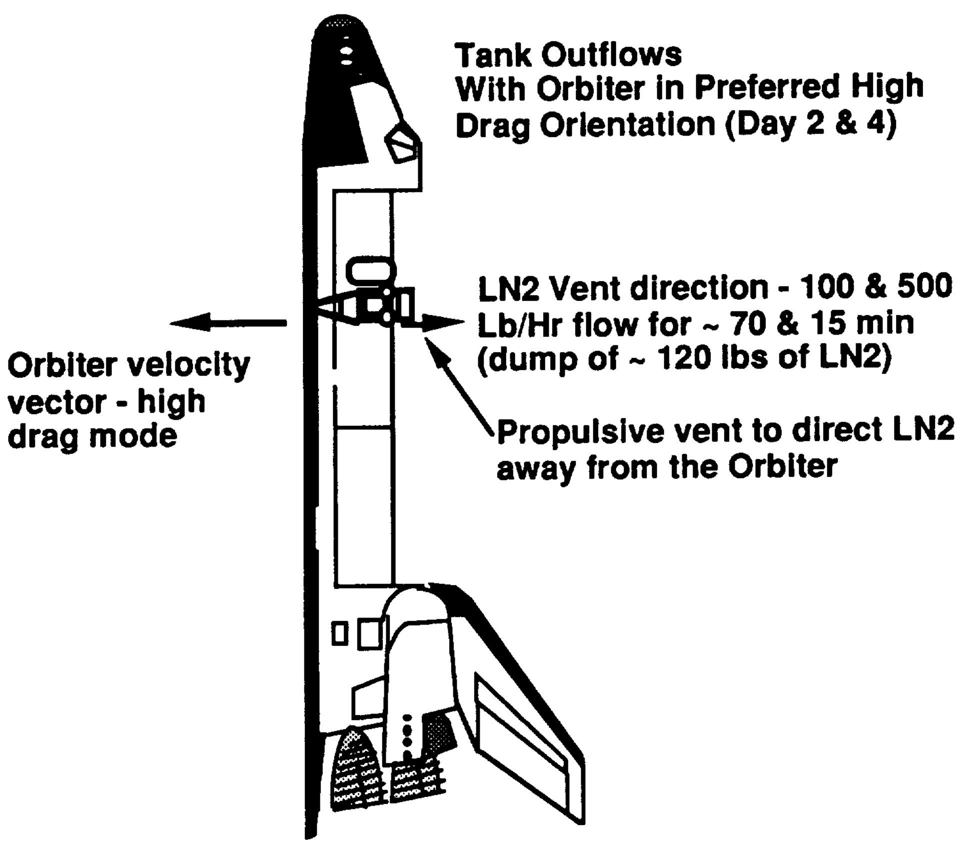

Figure 6.2-2 Orbiter Orientation Requirements

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Experiment Subsystem GSE Brace and Handling Sling - The MGSE concept depicted in Figure 7.1-2 provides for handling and lifting for the experiment subsystem that supports various fabrication,

- Provide Hardcopy Output
- Provide Utilities that Aid in Real-Time Decision Making
- Provide a Flexible, Easy-to-Use Graphical Interface
- Replay Old Data
- Provide a History File with an Experiment Log
- Provide a Support Rack with 336 kg (1400 lbs) Capacity, with Lift Eyes (Safety Factor of 5; 3182 kg (7000 lb) ultimate each)

The ground hardware consists of an EGSE microprocessor, the systems test equipment, a data tape recorder, personal computers, printers, data storage, and development hardware. Figure 7.2-1 is a block diagram of the ground electrical hardware.

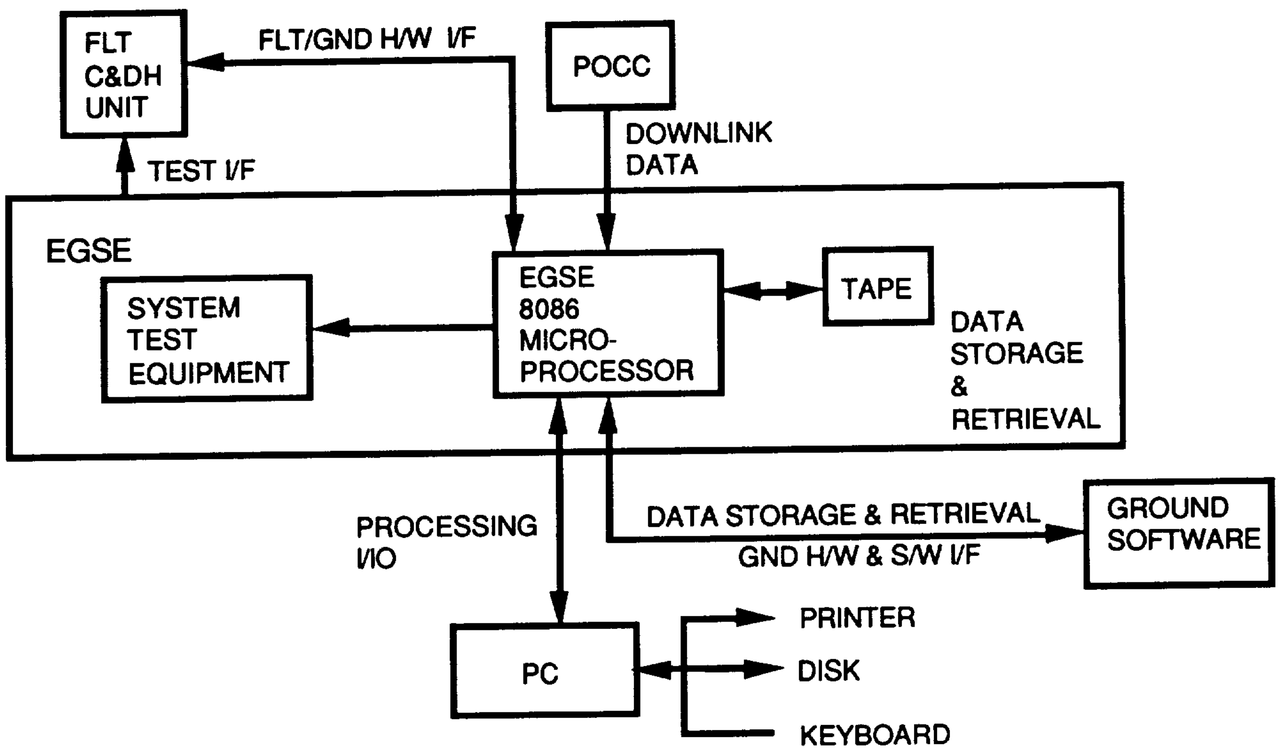

Figure 7.2-1 EGSE Hardware Block Diagram

The POCC system formats and directs the data to the EGSE after saving the data on disk. The EGSE receives the data via the EGSE micro-processor. The EGSE then processes and examines the data, saves the data to tape, and forwards the data to the PC for graphic display or report generation.

The System Test Equipment tests functions for the C&DH hardware. It will also accept commands to forward to the C&DH subsystem to permit preflight system checkout. Inflight data will be read and then analyzed, with the results forwarded to the PC. The PC will use disk for data storage and retrieval. The printer will be used for hardcopy.

<u>Sequence and Simulation Generator</u> - An automated creation of experiment test software similar to a compiler does syntax and semantics correctness evaluations of sequences which support sensors. Since actual executable sequences are stored on board the vehicle, the output is software that identifies the execution order of on-board sequences and provides variables such as time and ranges; This software uses commercial off-the-shelf (COTS) database with the output a listing of a file containing

the model of the sequence execution, and uplinking to the payload. The simulator can be used for POCC software development and validation, crew training, POCC operations training, Hitchhiker end-to-end testing, to support playback mode to edit and selectively re-record previously captured telemetry data; and to respond to commands and generate output telemetry based on preassigned, operator-selectable device behaviors or from an internally computed real time simulation. Figure 7.2-2 shows the interface between the simulation and the CONE hardware.

CONE Ground Software - The CONE ground software system performs control and analysis for all ground support activity before and after launch. The software interacts with the EGSE to facilitate preflight system validation as well as inflight and postflight system performance evaluation.

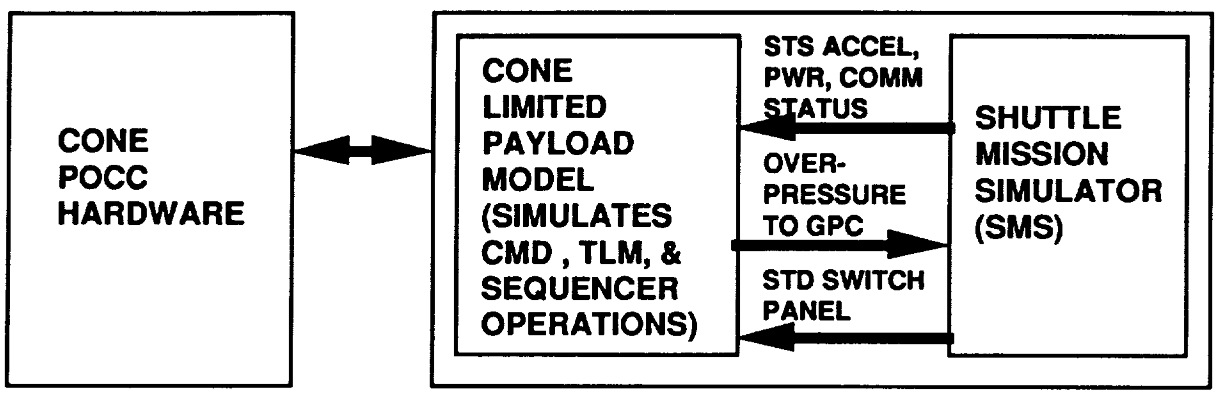

Figure 7.2-2 Simulation Interface

The five components of the Ground Software System are shown in Figure 7.2-3. They are the hardware handler, preflight processor, common analytic processes, man/machine interface, and inflight/postflight processor.

The common analytic processor houses all functions shared by Inflight/Postflight and Preflight processing. The two major subentities are the function scheduler and the common analytic functions. The function scheduler calls the appropriate function as requested by the inflight/postflight or preflight processor. The common analytic functions pass input and output data between themselves and both processors when performing a subordinate function for either. They also originate hardware control and command data and process hardware output data. Display data is shipped to the MMI. The functions include:

- Disk File Generation
- Fault Description
- Limit Checks
- Units Conversion
- Hardware Status Check
- Graphics Display Setup
- Instruments/Clock Monitor

The inflight/postflight processor provides for all CONE ground processing after launch. The major components are the inflight/postflight function scheduler, the inflight/postflight data separator, the inflight/postflight functions, and the report file generator. The function scheduler activates the appropriate processing function when passed control by either MMI or preflight processor.

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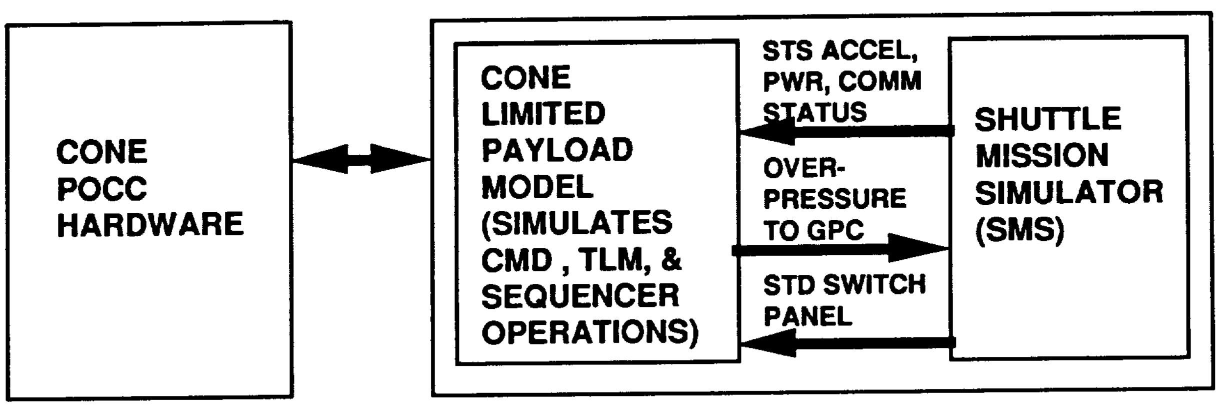

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assembly, test and integration needs. During the fabrication of the experiment subsystem elements it will provide for handling of individual elements (at the completed valve panel and tank assembly level) or the total experiment subsystem . Once the experiment subsystem elements are integrated together, the brace and the sling can accommodate all lifting and handling needs of the system.

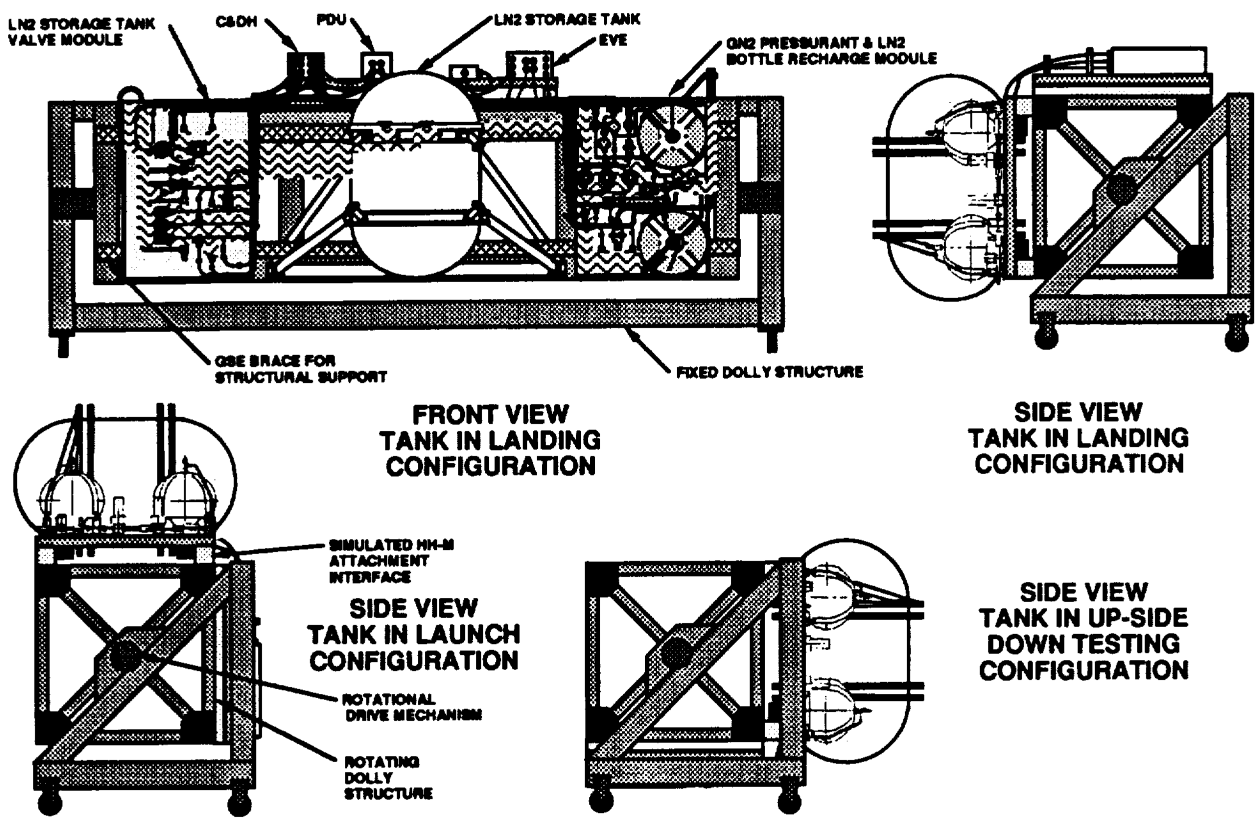


Figure 7.1-1 CONE System Support and Rotational GSE

The two GSE braces that form a component of the dolly system that allows the 3 basic elements of the experiment subsystem to be handled as a unit once plumbing connections are made between the elements are used with the sling to handle the entire experiment subsystem. Provisions are made for lifting eye attachments at those elements that may have to be handled individually and at the integrated level using this sling.

7.2 Electrical Ground Support Equipment (EGSE)

The EGSE provides command, control, calibration, simulation, ground 28 Vdc power to the payload, and data management of the support and experiment subsystems during ground test and checkout operations and also provides for all POCC flight control and monitoring needs. A major portion of the EGSE hardware is comprised of simulators, mission sequence and command generation system, monitoring system, display equipment and printer. In addition, a ground 28 vdc power supply, power subsystem support equipment, and electronics integration test equipment are provided. Ground

The data separator extracts flight data from its source (POCC for inflight, tape for postflight - indicated by the control and data interfaces with the Hardware Handler), and prepares it for use by the processing functions. The event ID is used by the function scheduler to determine the appropriate function to exercise. Flight data is used by the processing functions. These function carry out the experiment performance evaluation of the flight data provided by the data separator or preflight processor. They are activated by the function scheduler. They make use of the common analytic processes for intermediate processing. Output from these functions is sent to the MMI for display or to the report file generator. These functions include data compression and comparison, mathematical analysis, MLI interstitial pressure evaluation, TVS performance evaluation, outflow characteristics evaluation, chilldown line evaluation, heat exchanger accuracy, tank vent evaluation, and C&DH health evaluation.

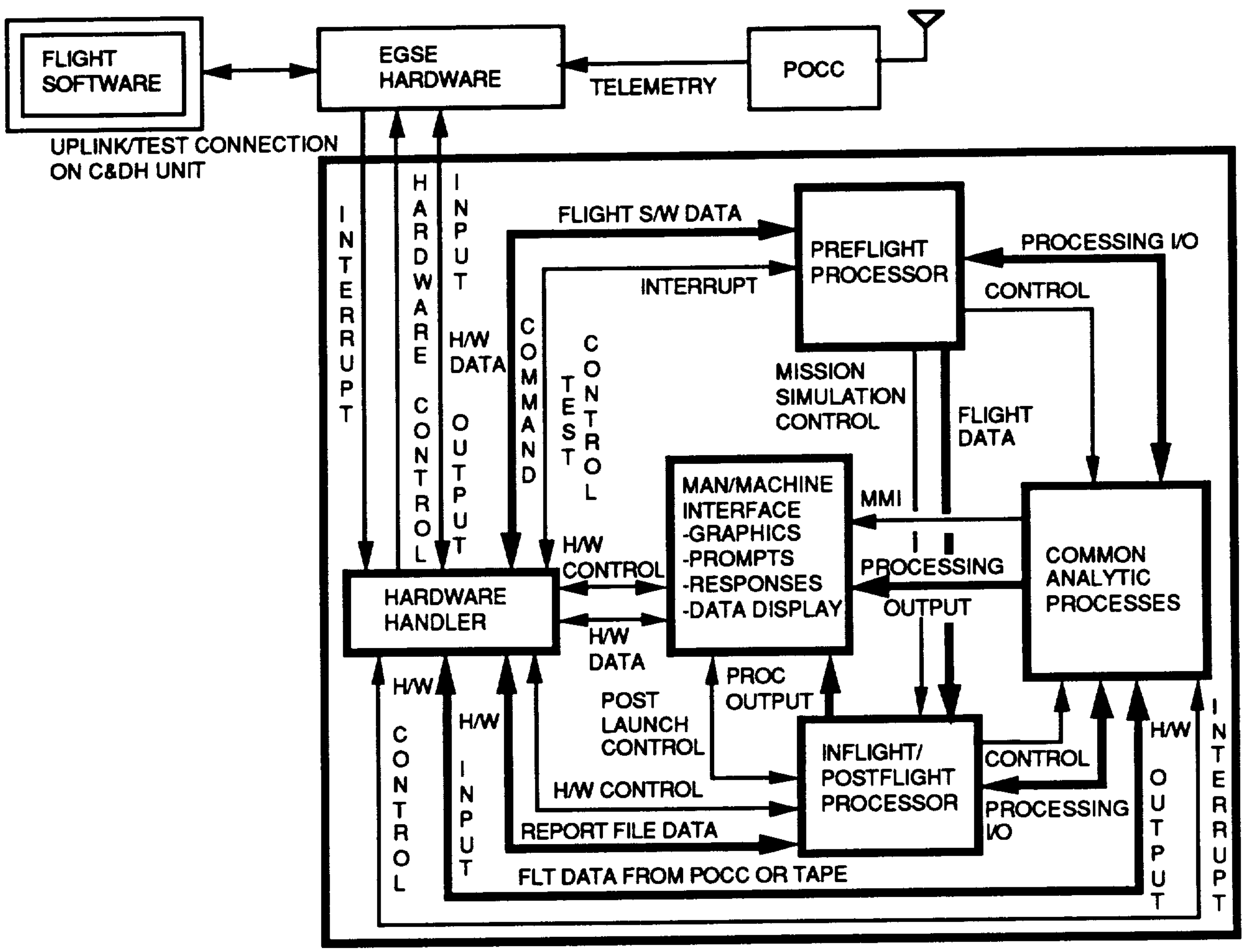


Figure 7.2-3 CONE Ground Software System

The man-machine interface (MMI) is composed of a keyboard/function key command decoder, a function scheduler, and MMI functions. The hardware handler detects a keyboard interrupt and passes control and data to the keyboard/function key command decoder which interprets the keyboard operator entry. Menu selection, display type, and hard copy selection are functions interpreted from the input. Control is then passed to the function scheduler. The MMI function scheduler selects the appropriate MMI function. These MMI functions include menu display, graphic display, cursor positioning decoder, hardcopy, error display, graphic file generation, and report file display. The

The ground command packet consists of up to 28 separate commands. The packet has a header with sync, byte count, source, type, and command packet number. Each packet has a checksum at the end. Each command has a control byte to determine if it is for immediate action or storage for later use. Each command has 3 command bytes of 8 bits each. The data structure of the telemetry packet for CONE will contain a header with the appropriate sync data followed by frame count and MET. The CONE data follows with information on commands, heaters, experiment sensors and valves, power distribution data, concluding with parity and a checksum. The packet data can then be split into the items on the device list, requested as raw data, or processed for analysis by subsystem. The data can also be split into status values, integer values, and real values. The status value is the byte level, the integer value is the word value, and the real value is the floating value.

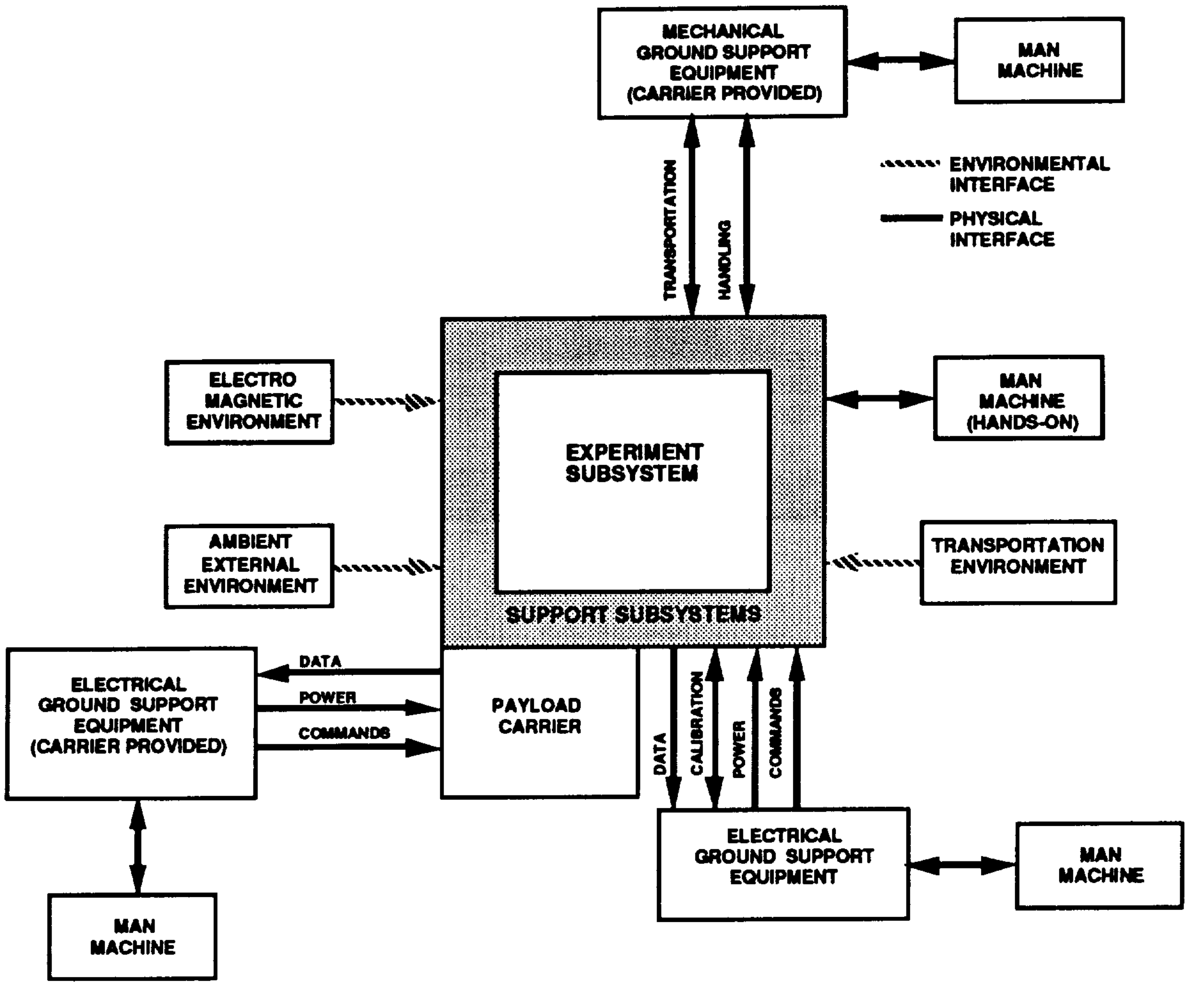


Figure 8.0-2 CONE Element Interfaces After Carrier Integration

The CONE flight element is integrated to the carrier to form the CONE P/L to ground element interfaces after STS integration required to support integrated P/L checkout and test needs with the Shuttle Orbiter. Both MGSE and EGSE interfaces are needed to support individual subsystem and integrated system level test and checkout, as well as final servicing of LN2 and GN2 prior to launch. All of these interfaces are direct physical interfaces. At this point in the flow, STS provided EGSE will be used for checkout of the TDRSS/NASCOM/POCC communication interface that will be used during flight, as well as electrical checkout of Orbiter and carrier interfaces to the CONE. The capability will still exist to interface CONE system EGSE for test and checkout independent of carrier or STS provided equipment.

Indirect environmental interfaces have to be accommodated and controlled throughout this portion of the program flow which includes controlling EMI/ESD and providing a clean and thermally controlled working environment for the CONE while inside the Orbiter bay on the ground.

Prior to launch, the CONE will be configured for ascent (The storage tank will either be locked-up or the TVS will be on in case an abort landing should be required). This final configuration will be accomplished for the AFD SSP by the cabin closeout ground crew prior to flight crew egress. At launch the CONE is powered down with no monitoring occurring. Figure 8.0-3 shows the CONE P/L flight element interfaces pre-launch after Shuttle integration.

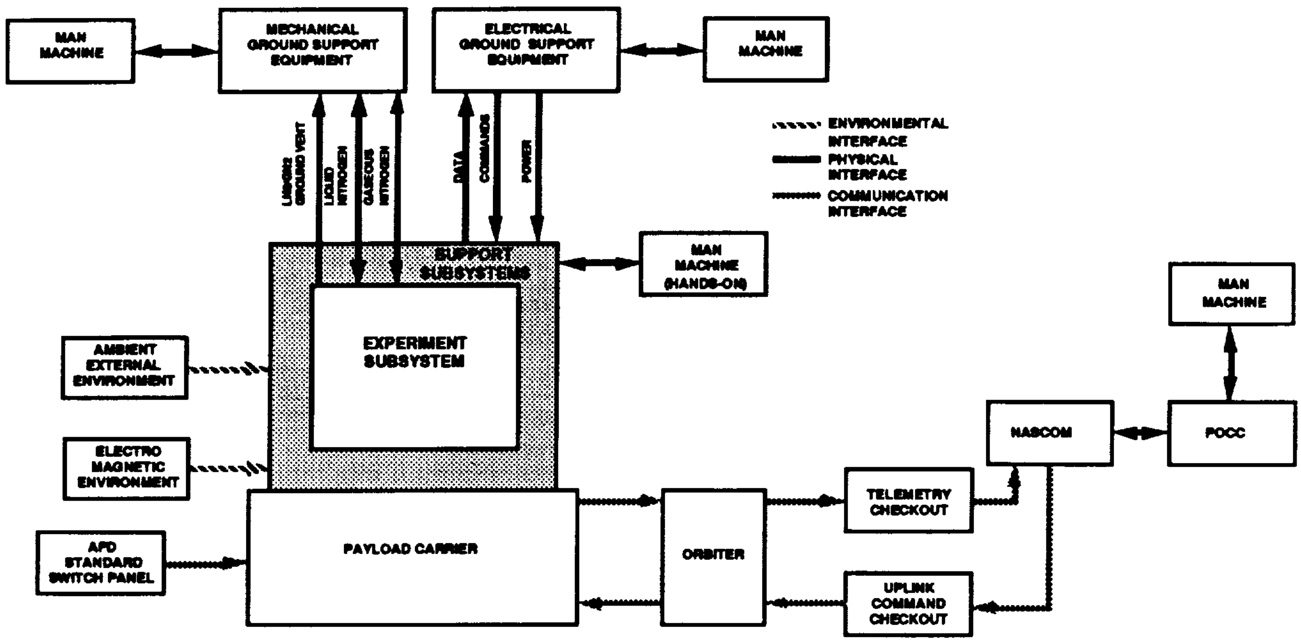


Figure 8.0-3 CONE P/L Flight Element Interfaces Pre-Launch After Shuttle Integration

During ascent, the CONE will be subjected to the launch environment. Environmental interfaces to CONE during the launch are depicted in Figure 8.0-4.

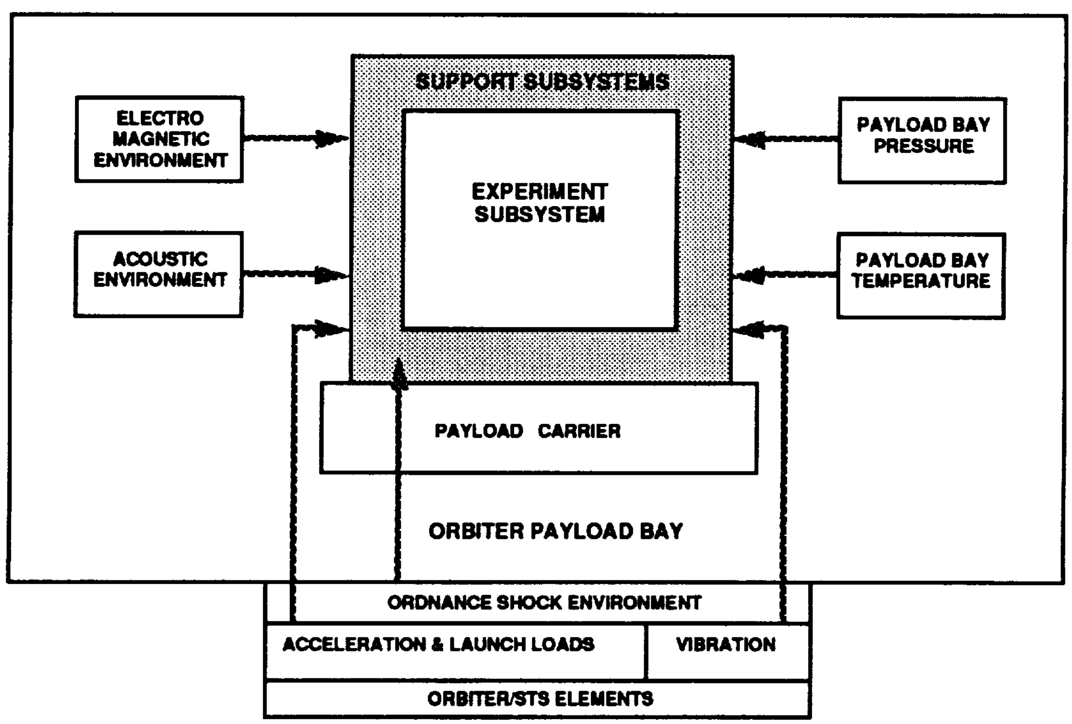


Figure 8.0-4 CONE P/L Environmental Launch Interfaces

8.0 INTERFACES

The CONE System is comprised of the CONE flight element which is divided into an Experiment Subsystem and associated Support Systems and the CONE ground element which is divided into Mechanical/Electrical Ground Support Equipment, Payload Operations Control Center equipment and Experiment PI's and support personnel. Internal interfaces reside within the CONE System and consist of mechanical, electrical, thermal, and man/machine hands-on interfaces that are used during various mission phases. Figure 1.6-1, shown previously, provided a definition of the CONE System and the functional interfaces required to operate the system.

For the CONE System to functionally operate it must interface directly and indirectly with external support functions consisting of the following:

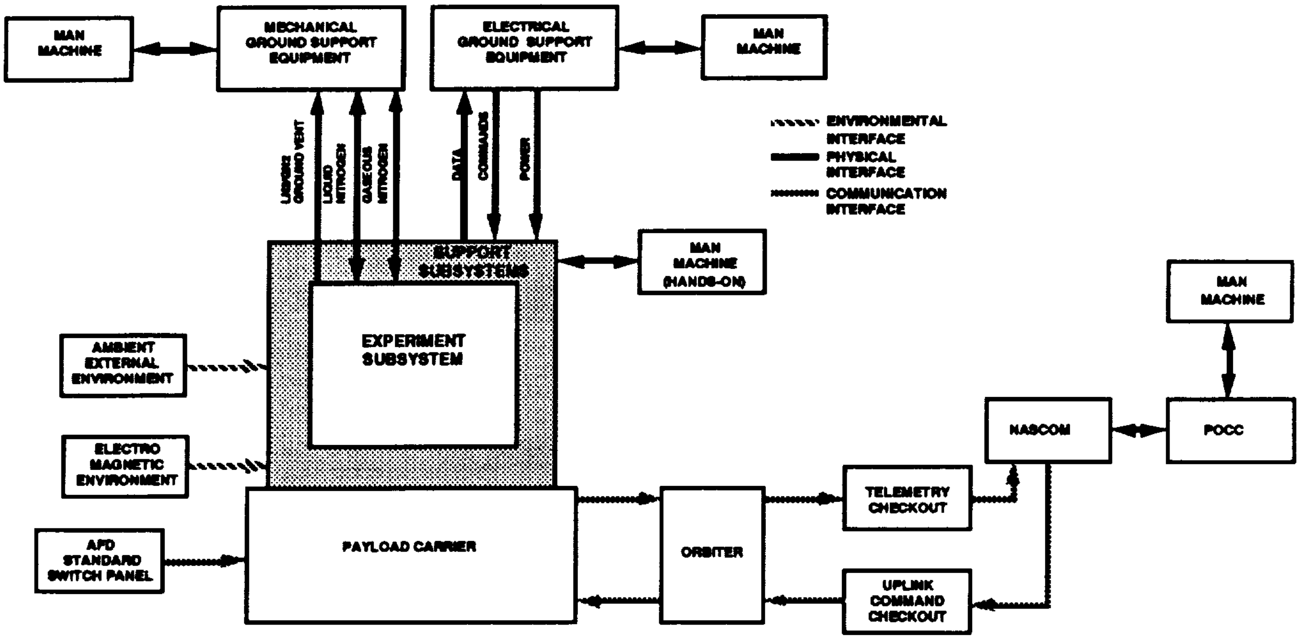
- HH-M carrier for mechanical support and electrical services and other support accommodations provided by the Orbiter
- Environmental interfaces with both the Orbiter and the HH-M carrier
- Via the HH-M and the Orbiter command and monitoring interface using the TDRSS
- Via GSFC the command and monitoring needs with the POCC are provided
- While at GSFC or KSC ground processing and servicing needs are provided
- An additional interface between the POCC and the JSC Mission Control Center (MCC) is shown for support and coordination of the CONE mission at JSC where real-time mission support is required

Direct interfaces with the carrier and through the carrier to the Shuttle Orbiter consist of the following:

- Manually controlled storage tank ground LN2 fill/drain line and servicing port provides tank access to loading/detanking GSE for both the normal launch vertical attitude and the abort landing horizontal attitude. This line is not used for any flight purpose.
- Manually operated storage tank ground GN2/LN2 vent line and servicing port provides access to the tank ullage gas at the top of the tank in both tank attitudes and allows the tank to be loaded to a maximum of 95%. This line is not used for any flight purpose.
- Manually operated GN2 pressurization line and servicing port provides access to each pressurant bottle for ground pressurization to flight pressure 20700 kN/m^2 (3000 psig). This line is not used for any flight purpose.
- An Orbiter in-bay low flow vent 13.6 kg/hr (30 lb/hr) maximum accommodates storage tank venting from the TVS, CHX and OHX only and also tank and vacuum jacket over-pressure relief protection. This vent has redundant effluent discharge capability.
- The Orbiter high flow space vent accommodates storage tank outflow at rates up to 227 kg/hr (500 lb/hr) and is activated/operated only after the P/L bay doors are opened on-orbit.
- Ground control for command and data, as well as 28 vdc power interface to EGSE.
- A direct interface with AFD standard switch panel functions thru carrier provided accommodations.
- Command and data interface thru the carrier to Orbiter systems.
- 28 vdc power interface thru the carrier to Orbiter systems.
- Physical mechanical attachments of CONE elements to the carrier structure.
- Via carrier and Orbiter services a communication link for command control and data monitoring during flight is provided using the TDRSS.

The flight element to ground element interfaces are required to support the assembly and test needs of the system before pack and ship to GSFC where the CONE will be integrated to the HH-M carrier. Both MGSE and EGSE interfaces are needed to support individual subsystem and integrated system level test and checkout. All of these interfaces are direct physical interfaces.

Indirect environmental interfaces have to be accommodated and controlled throughout this portion of the program flow which includes transportation both within the manufacturing facility and shipment to



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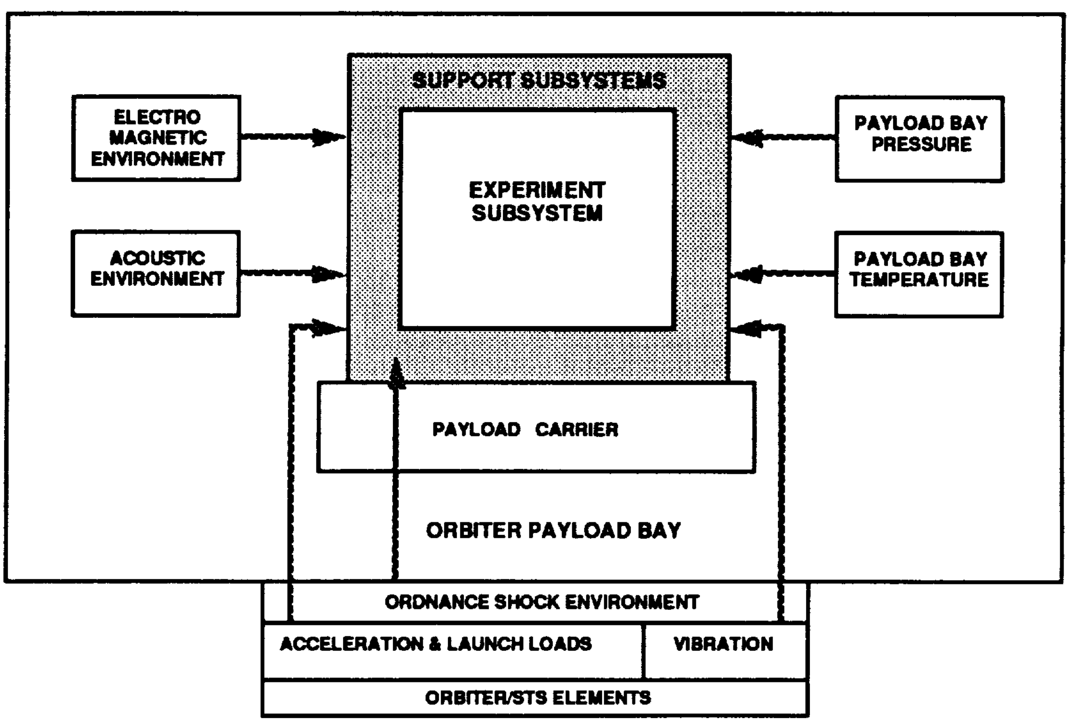

Figure 8.0-4 CONE P/L Environmental Launch Interfaces

9.0 OPERATIONS

CONE operations begin with those assembly and test activities required to validate/certify the design and performance characteristics to be able to accomplish the mission objectives. Mission operations encompass all ground processing, carrier and Orbiter pre-launch integration and on-orbit experimentation performed by the payload. Operations will be conducted at 1) the contractor facility during assembly, integration and testing; 2) GSFC for HH-M carrier installation; 3) KSC for CONE P/L final assembly, integration to the Orbiter and pre-launch servicing, as well as post-mission deintegration and contingency operations; and 4) the POCC at GSFC for flight control.

Organizational Roles and Responsibilities - The organizations that play a part in the CONE program are listed in Table 9.0-1 along with the associated functions of each.

Table 9.0-1 Mission Requirements From Organizations

SHUTTLE

LAUNCH
ORBIT
PAYLOAD BAY DOORS OPEN
ATTITUDE CHANGE
RCS THRUSTER FIRINGS
CREW CONTROL [SSP]
PROVIDE PAYLOAD POWER
UPLINK OF GROUND COMMANDS
UPLINK OF SEQUENCE AND TIMING CHANGES
DOWNLINK OF PAYLOAD DATA
LANDING

HITCHHIKER MPESS

TRANSFER TIME
TRANSFER DATA
TRANSFER POWER
STRUCTURAL SUPPORT
SUPPORT PLATES

POCC

PROCESS DOWNLINK
PREPARE UPLINK
ANALYZE DOWNLINK DATA
PREPARE TAPES FOR SCIENTISTS

LERC

MANAGE PROGRAM
DEFINE GFP
COORDINATE INTERCENTER ACTIVITY
DEFINE EXPERIMENT

KSC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INTEGRATE PAYLOAD
INSTALL PAYLOAD IN SHUTTLE
END-TO-END TESTING OF PAYLOAD

GSFC

RECEIVE PAYLOAD
INSPECT PAYLOAD
INSTALL PAYLOAD ON MPESS TOP
SYSTEM TEST PAYLOAD
SHIP PAYLOAD TO KSC
TRAIN POCC CREW

JSC

RECEIVE AND TRANSMIT COMMANDS
RECEIVE AND TRANSMIT TELEMETRY
TRAIN CREW

9.1 Assembly and Verification

The major elements of the experiment subsystem are fabricated and assembled at the tank and module level and then are integrated together with interconnecting plumbing into the assembled experiment subsystem which has previously been defined in section 4.0. Support subsystem structural, avionic and thermal elements as defined in section 5.0 complete the CONE flight system. All assembly operations will utilize the support and rotational dolly defined in section 7.0. Testing will be accomplished throughout these various stages of hardware build-up and include component, subsystem, system, and integrated segment verification over the test program life.

9.1.1 Assembly

Hardware Build-up Approach - Fabrication and assembly of the CONE payload flight element will be dominated by the LN2 storage tank. The other elements of the experiment subsystem are contained into two compact component modules located on either side of the tank as shown in Figure 9.1.1-1. These three elements comprise the experiment subsystem and form the heart of the hardware of the CONE flight system. Other support subsystem elements are added for electrical power, C&DH, thermal and structural (specifics follow later in this section) until the entire system is configured.

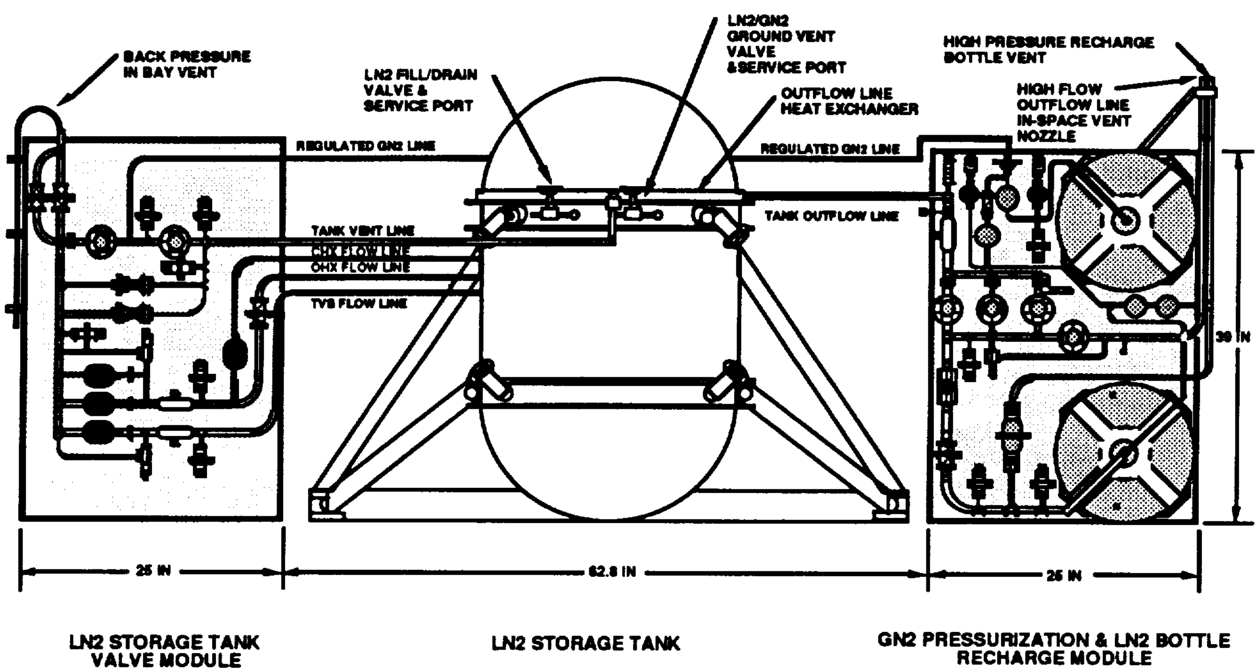

Figure 9.1.1-1 Experiment Subsystem Hardware with Insulation Removed

LN2 Storage Tank - The assembly sequence for the LN2 storage tank is depicted in Figure 9.1.1-2 and shows the tank build up required to complete the unit. For each phase an overview of the installation steps are shown along with the the required tooling to support the operations. Starting with the LAD and LAD subassembly the tank essentially is built-up from the inside to the outside. This process requires that stringent checks be accomplished as the process progresses. Once PV and VJ shell welds are made correcting internal problems that may arise becomes extremely difficult and costly. The tooling shown also supports the in-line tests accomplished to assemble the tank which are further defined in this section.

LN2 Storage Tank Valve Module - All components that interface with the back pressure vent and provide LN2 storage tank pressure relief or isolation for TVS, CHX, OHX flow rate control and tank venting/pressure introduction, as well as instrumentation for flow monitoring are accommodated by this module. The entire module is unitized by a 1.6 cm (5/8 in) thick fiberglass mounting plate that is sized 63.5 cm (25 in) wide by 99 cm high (39 in). Components and plumbing mount to the module plate which in turn mounts to the support and rotational dolly which simulates the HH-M interface.

GN2 Pressurization and LN2 Bottle Recharge Module - Components associated with pressurant storage, ground servicing, regulation and distribution, as well as the LN2 storage tank outflow line

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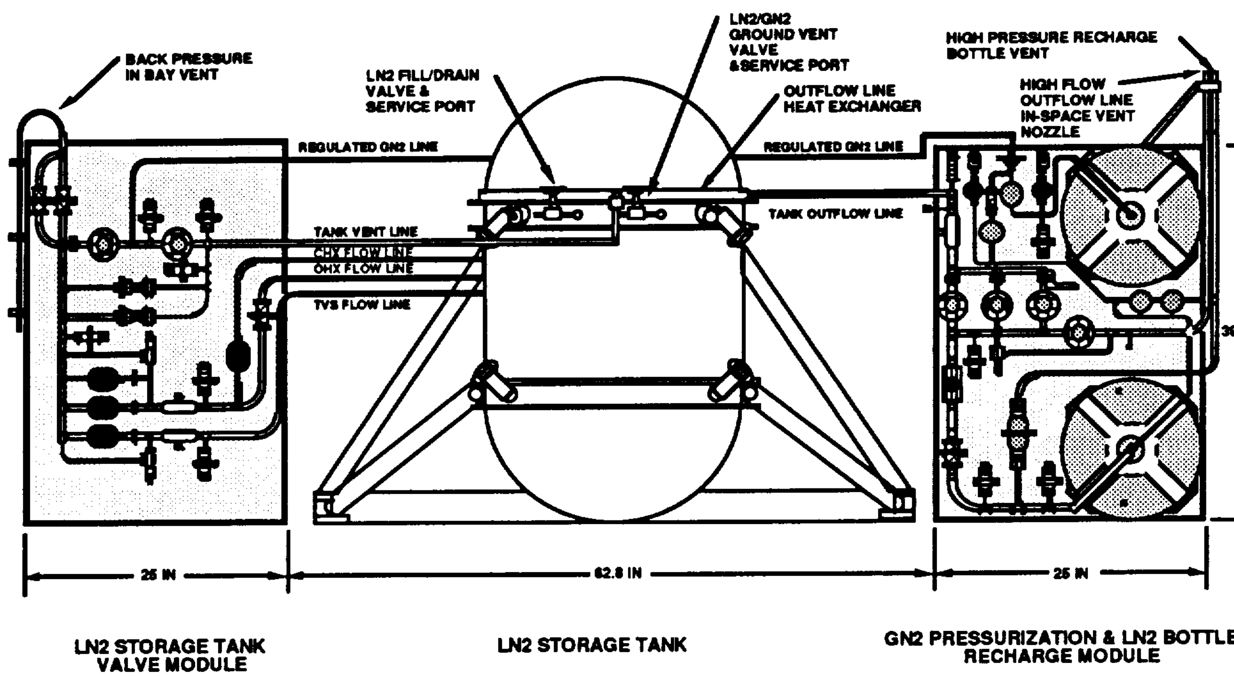

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GN2 Pressurization and LN2 Bottle Recharge Module - Components associated with pressurant storage, ground servicing, regulation and distribution, as well as the LN2 storage tank outflow line

Once the cargo bay doors have been opened, the CONE carrier and experiment can be activated from the AFD SSP and the CONE mission events can be initiated. Command control and monitoring with the POCC will be accomplished thru the carrier via the Orbiter and its communication interface with TDRSS. CONE P/L interfaces on-orbit are shown in Figure 8.0-5.

While on-orbit the CONE will be exposed to the listed environments, which for the greater part of the mission will not be mission controllable. Certain attitude and thrusting needs are required for selected experimental needs.

The CONE POCC interfaces to the flight element CONE payload through the NASCOM network supplied by GSFC and coordinated with Orbiter operations through the JCS Mission Control Center in Houston (MMC-H). Data will be received on a random basis determined by Orbiter operations and TDRSS usage. Uplink command files, to modify/interrupt planned automatic events, have to be coordinated with MMC-H for transfer to the Orbiter. Orbiter attitude, position altitude and other ephemeris data required at the POCC can be requested.

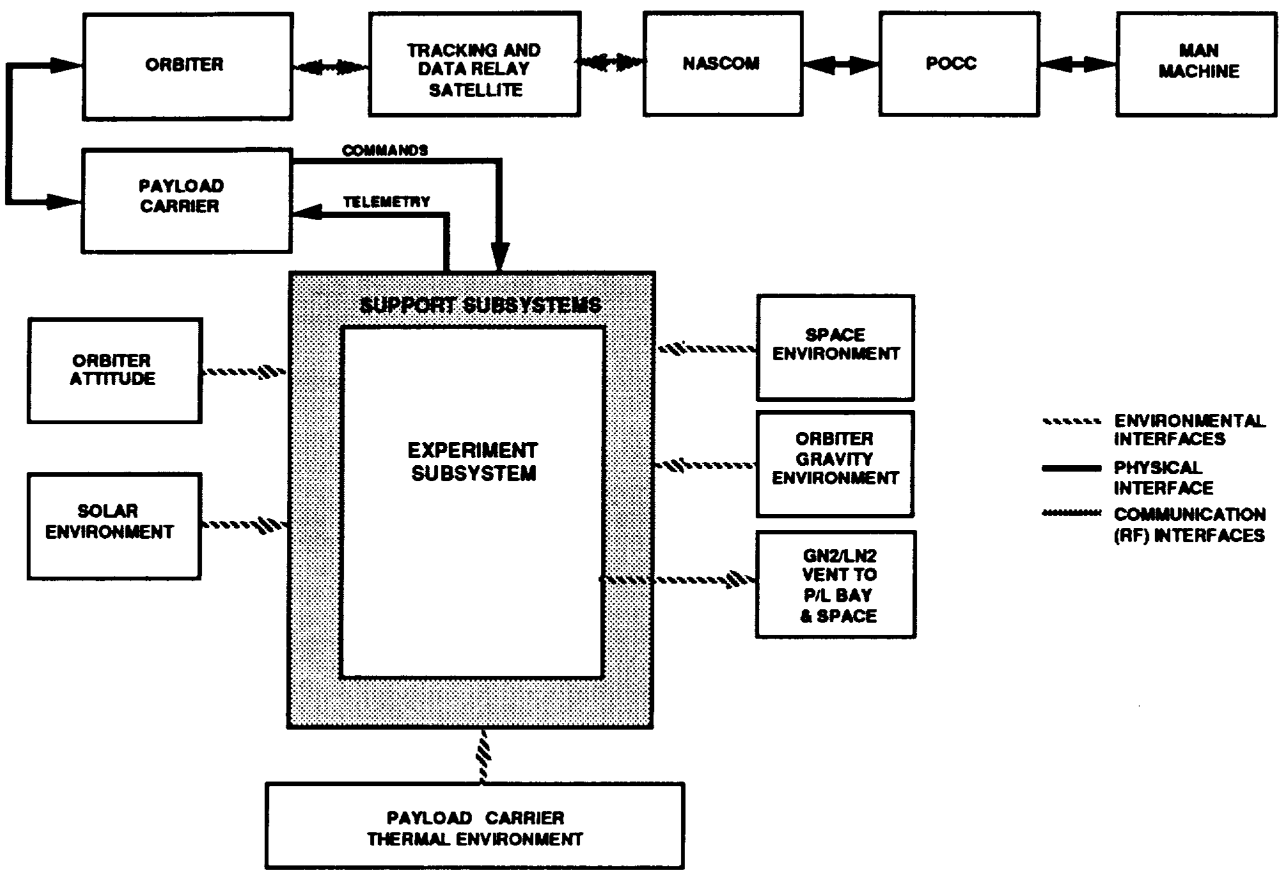

Figure 8.0-5 CONE P/L On-Orbit Interfaces

Module Insulation and Cabling Details - Figure 9.1.1-4 shows the details of the LN2 storage tank valve module insulation with respect to which components are insulated and those pieces that are exposed. Figure 9.1.1-5 shows the LN2 storage tank valve module with the cabling wire harness installed to electrically operated valves and instrumentation. The wire harness has been divided into two unique Control/Status and Instrumentation sections. The Control/Status portion of the harness provides operating power from the EVE for valve control and also routes valve position status to the C&DH via the EVE. The control and status portions of this harness will be separated/shielded from one another. The Instrumentation portion of the harness provides transducer/device excitation power from the C&DH or associated device electronics and also routes data signals to the C&DH or associated device electronics. Where required, power and signal elements of the Instrumentation section of the harness will also be separated/shielded from one another. Figure 9.1.1-6 and -7 shows similar details for the GN2 pressurization & LN2 bottle recharge module.

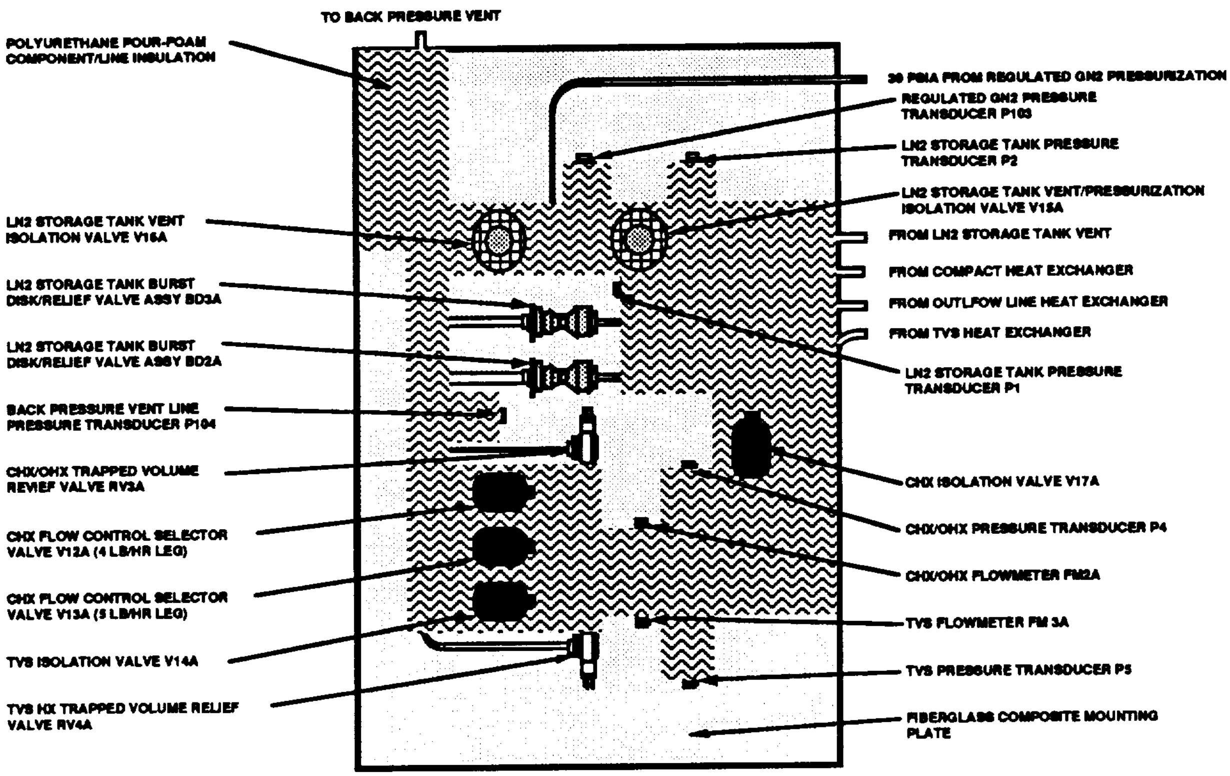

Figure 9.1.1.-4 LN2 Storage Tank Valve Module Insulation

Supports for the individual wires and cables of the harness are provided for direct mount to the module baseplate or to the top of the foam insulation system. Certain cabling clamps will be located within the foam block to secure cabling that has to be routed to various component locations. These support clamps extend through the foam block so that they are secured to the module base plate in order to provide adequate structural support for the harness elements. Clamps interfacing with the foam must be properly placed before performing foam installation.

As the main harness bundle leaves the module, interface connectors are provided so that the entire module with its harness can be handled and tested as a unit. The module harness itself also is a unique element that can be handled, installed, tested, or removed as a unit. All of the wires/cables of the harness are routed to the right side of the module and progressively become larger bundles until they exit the module for routing to the avionics system elements.

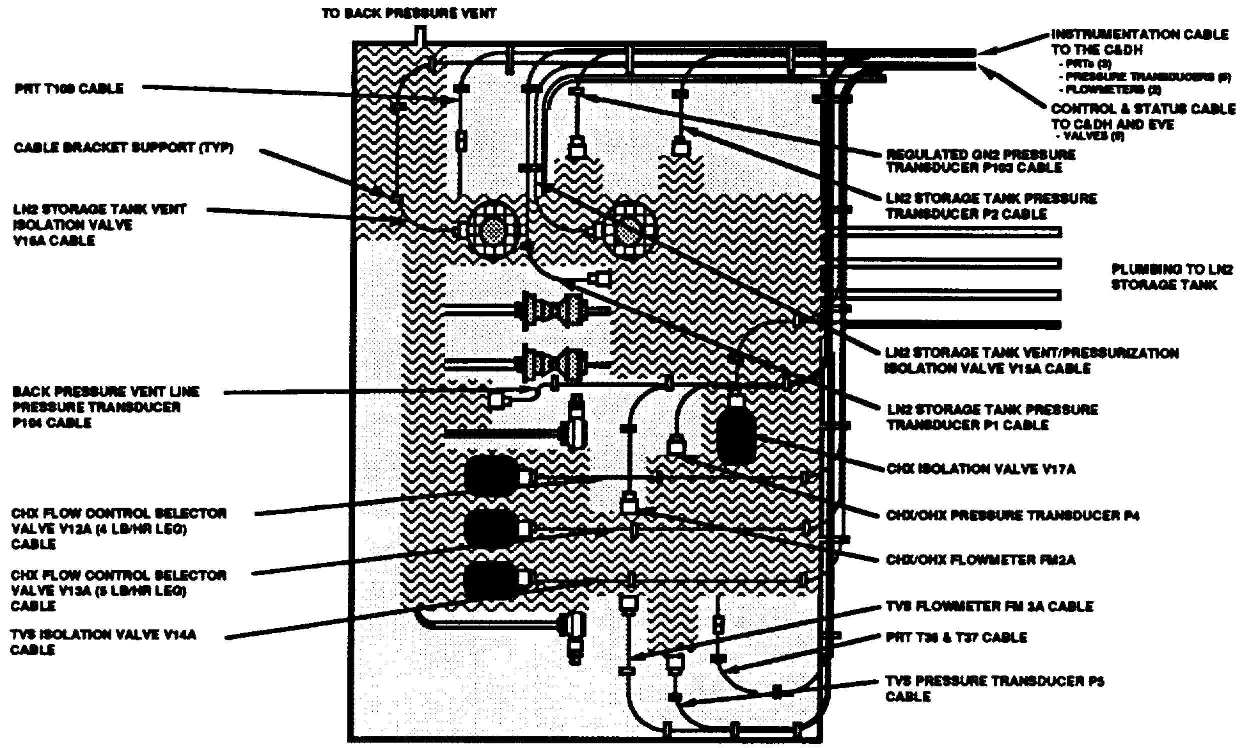

Figure 9.1.1-5 Storage Tank Valve Module Cabling

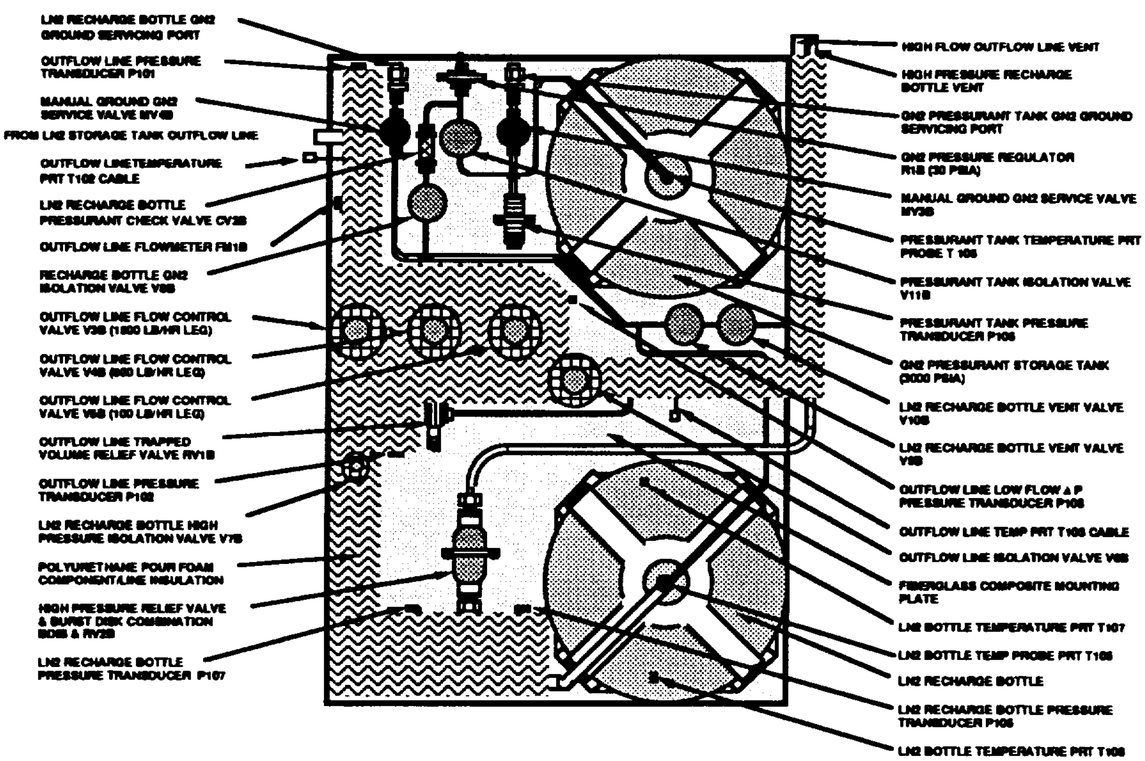

Figure 9.1.1-6 GN2 Pressurization and LN2 Bottle Recharge Module Insulation

and the LN2 recharge bottle are assembled into a self contained module with a mounting plate system identical to the LN2 storage tank valve module.

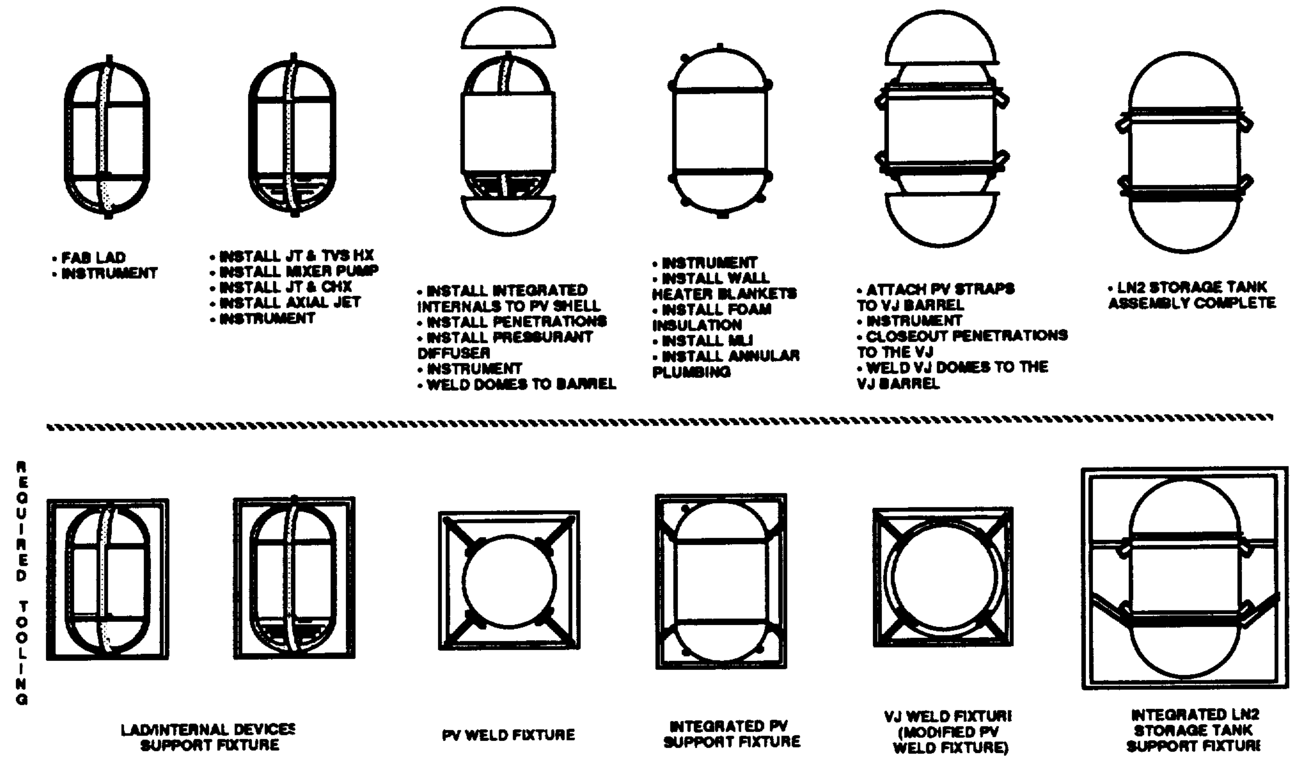

Figure 9.1.1-2 LN2 Storage Tank Assembly Sequencing and Supporting Tooling

Experiment Subsystem Hardware Insulation Layout - Once the LN2 storage tank, modules and interface plumbing lines to the modules have been proof pressure tested, leak checked and acceptance tested for component and instrumentation function, the noted areas will be insulated with a polyurethane pour foam system so that all areas exposed to LN2 or cold GN2 will be protected for ground operations and testing. This will allow a large portion of acceptance, functional and performance testing to take place at ambient rather that a more costly vacuum chamber environment. The installation procedure for the foam installation is as listed in Table 9.1.1-1.

For electrically operated valves and instrumentation all valve operators and connectors will protrude from the insulation as shown in Figure 9.1.1-3 which shows the experiment subsystem after insulation application has been completed. Manual fill and drain valves will be insulated with servicing ports exposed.

Table 9.1.1-1 Polyurethane Foam Component/Line Installation Procedure

• SURFACE PREPARATION	
	- solvent wipe
• SURFACE PROTECTION	
	- apply Teflon tape with a 50% spiral overlap to all surfaces that will be exposed to the foam insulation
	NOTE: This step is required should insulation ever have to be removed for component access.

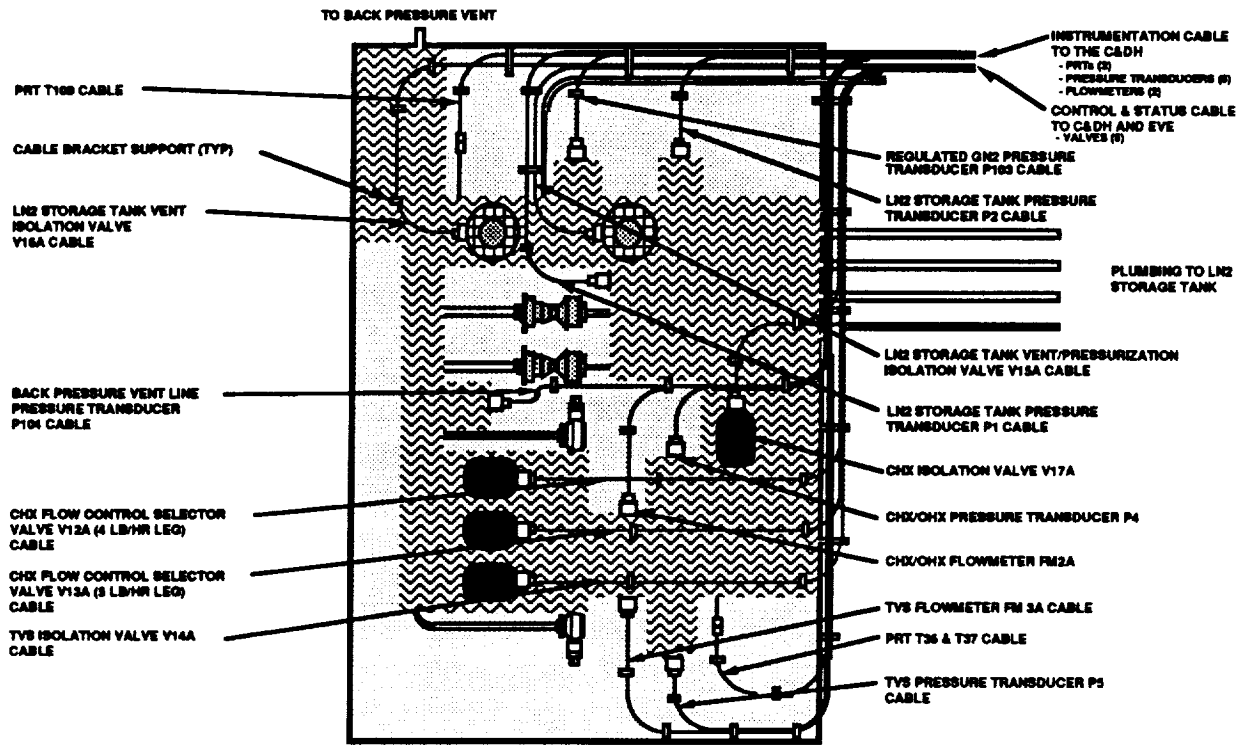

Figure 9.1.1-5 Storage Tank Valve Module Cabling

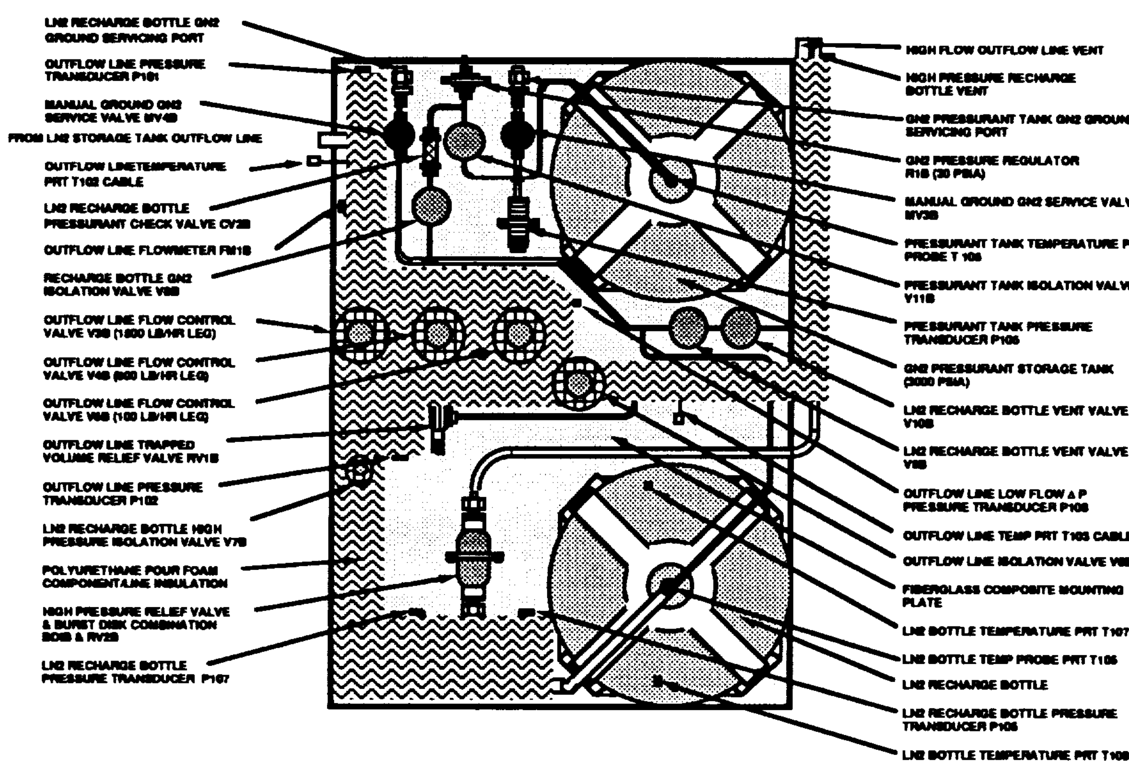

Figure 9.1.1-6 GN2 Pressurization and LN2 Bottle Recharge Module Insulation

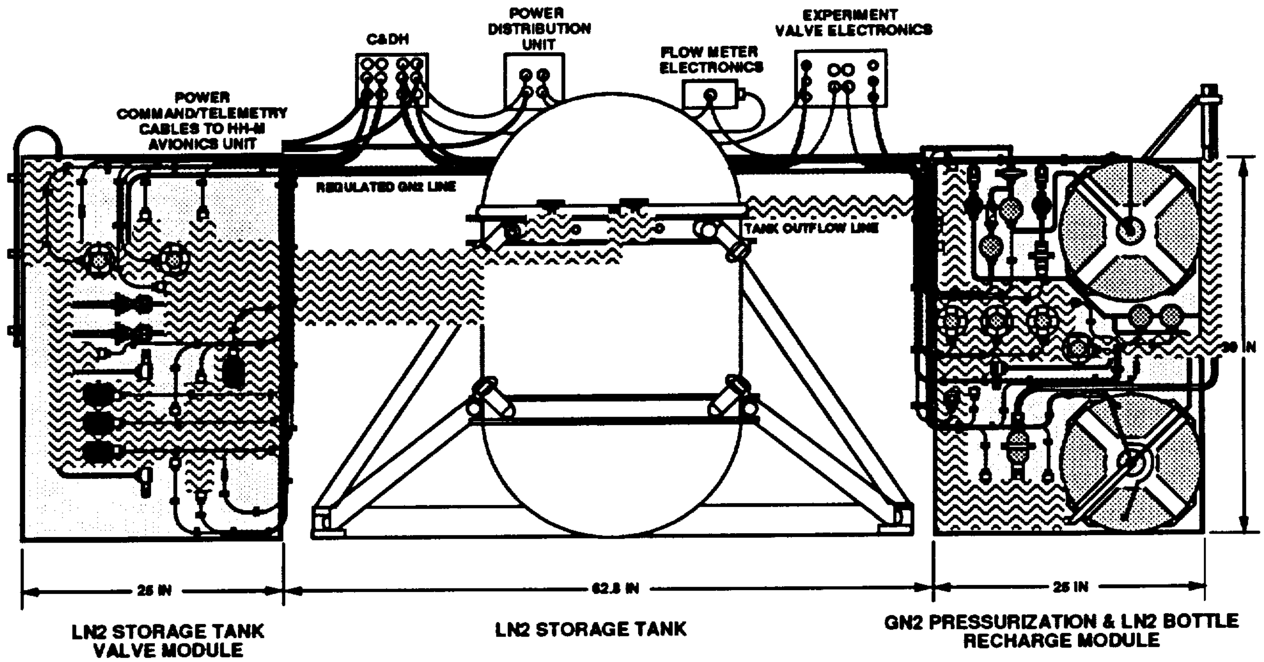

Figure 9.1.1- 10 CONE System Configuration Without HH-M Carrier

CONE Avionics Assembly - The GEOMOD depiction in Figure 9.1.1-11 is an expanded view of the elements of the avionics subsystem assembly on the top of the HH-M mounting plate structure along with the interconnect cabling harnesses. Two plates accommodate unit mounting and cable routing. This configuration has the units in close proximity to one another and minimizes cable lengths to both the HH-M avionics unit and the experiment subsystem.

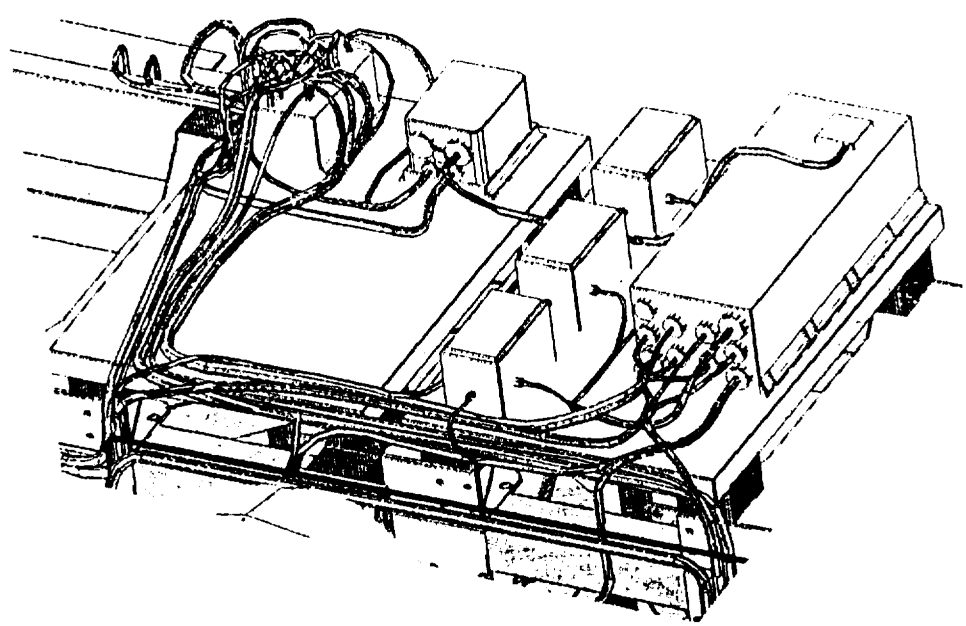

Figure 9.1.1-11 CONE Avionics Assembly

9.1.2 Verification and Test

The philosophy and approach by which the CONE hardware testing, checkout and verification program will be accomplished is defined in this section. A Test and Verification Plan has been prepared that provides a disciplined approach to defining, documenting, conducting and controlling all phases of the test and verification program. All aspects of the CONE test and verification program are addressed with respect to the definition of test method, test description, required criteria, approach and controls that will have to be instituted for the following testing categories which may occur at various component, subsystem, system and integrated segment levels over the test program life:

- In-line: These tests verify the requirements for subassembly and component and are considered as conditional acceptance tests that constitute a data base for the final system acceptance tests. Such tests are performed at key points in the fabrication sequence to verify hardware integrity before performing steps that would preclude efficient repair or replacement. Tests shall be performed at the component level, as required, in order to verify compliance with design requirements and for the purpose of certifying components for use. Whenever possible, off-the-shelf components shall be selected to meet CONE design requirements without further vendor or Martin Marietta testing.
- Acceptance: Acceptance tests are performed at all levels of assembly commencing with piece-part acceptance and proceeding through post manufacturing checkout to any formal testing required by the end-item specification to verify compliance with established criteria and acceptable go/no-go limits.
- Functional: Tests in this category are operating tests that are normally derived for the purpose of performing minimal design operation to verify proper operation of the hardware with respect to such items as control logic, valve operation, instrumentation, thermal control, EGSE control, pressure integrity, outflow and tank capabilities, as well as servicing, off-loading and abort considerations. Requirements for functional tests are identified in end item design specifications and are performed at either ambient or the environmental exposure conditions.
- Environmental: This category of test will verify operation over the expected extremes of thermal, vacuum, vibration/acoustics, and electromagnetic environments. The intent of these tests is to verify the experiment design and operational, capabilities of critical subassemblies to properly function in the flight environment.
- Qualification: Qualification tests are formal, contractual demonstrations that the design, implementation and manufacturing methods have produced hardware at component, assembly, subsystem or system levels which conform to specification requirements. Test levels shall account for variations in hardware and environments and provide a factor of safety.
- Performance: These operating test verify that all systems, circuits and software are operating as required by design specifications and includes separate checks of all contingency, back-up, and off-nominal operational checks.
- Developmental: This category of testing is conducted to verify design concepts, assure compliance to performance requirements, and establish safe operating or performance limits/conditions for the equipment being evaluated. They are required when program risk is unacceptable to rely on undemonstrated configurations and where performance/design concerns cannot be deferred to the normal test flow for resolution. Breadboards, brassboards, structural models, and mock-ups are used in support of development testing.

Other Verification Methods - Other verification methods complement the full-up test approach provided above and will be used where appropriate to augment this primary method. Although test nominally provides the most credible proof of performance capability, judicious selection of the listed verification methods shall be made where cost effective.

Test and Verification Program Objectives - Objectives of the test and verification program are expanded upon below:

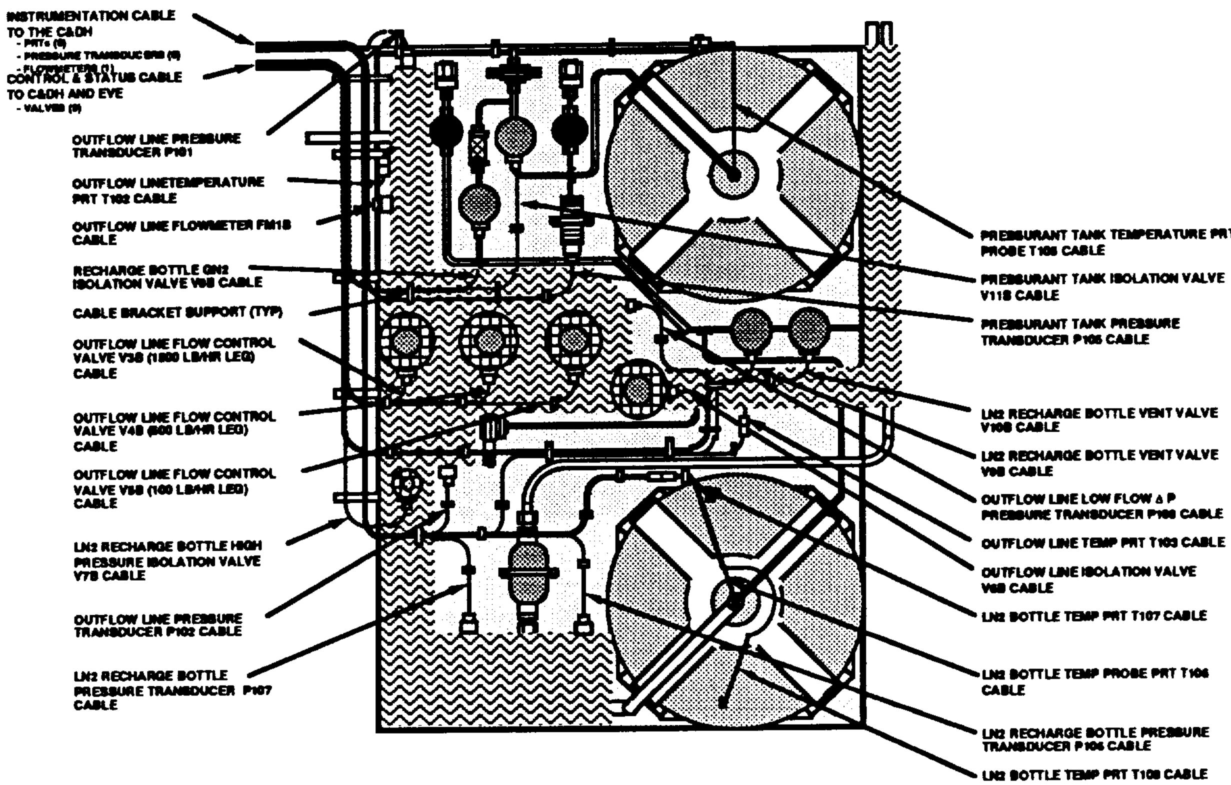

Figure 9.1.1-7 GN2 Pressurization & LN2 Bottle Recharge Module Cabling

Valve Module Plumbing - Figure 9.1.1-8 & -9 shows an expanded view of the LN2 storage tank valve module and GN2 pressurization & LN2 bottle recharge module, respectively, installation mounted in its flight configuration to the HH-M carrier. They show the GEOMOD baseline design for this portion of the experiment subsystem. For purposes of clarity so that module details remain visible the foam insulation system has not been shown. Views also show the cabling/wire harness installation and routing without the foam. Both figures show the modules installed to the the HH-M support structure with the modules attached to the HH-M provided attachment plates.

CONE System Configuration (Shown Without HH-M Carrier) - Figure 9.1.1-10 shows the integrated CONE system with insulation and cabling wire harness installed to both modules, the LN2 storage tank and all of the avionics system. Supports for the individual wires and cables of the harness are provided for direct mount to the module baseplate, to the top of the foam insulation system or to supports mounted to the top plates where the avionics are mounted. Two harness assemblies from the modules to the avionics boxes which also interconnect the avionics subsystem boxes with themselves are provided to interface with the module wire harnesses. A separate harness (HH-M provided) connects the CONE avionics boxes to the HH-M avionics unit.

9.1.2 Verification and Test

The philosophy and approach by which the CONE hardware testing, checkout and verification program will be accomplished is defined in this section. A Test and Verification Plan has been prepared that provides a disciplined approach to defining, documenting, conducting and controlling all phases of the test and verification program. All aspects of the CONE test and verification program are addressed with respect to the definition of test method, test description, required criteria, approach and controls that will have to be instituted for the following testing categories which may occur at various component, subsystem, system and integrated segment levels over the test program life:

- In-line: These tests verify the requirements for subassembly and component and are considered as conditional acceptance tests that constitute a data base for the final system acceptance tests. Such tests are performed at key points in the fabrication sequence to verify hardware integrity before performing steps that would preclude efficient repair or replacement. Tests shall be performed at the component level, as required, in order to verify compliance with design requirements and for the purpose of certifying components for use. Whenever possible, off-the-shelf components shall be selected to meet CONE design requirements without further vendor or Martin Marietta testing.
- Acceptance: Acceptance tests are performed at all levels of assembly commencing with piece-part acceptance and proceeding through post manufacturing checkout to any formal testing required by the end-item specification to verify compliance with established criteria and acceptable go/no-go limits.
- Functional: Tests in this category are operating tests that are normally derived for the purpose of performing minimal design operation to verify proper operation of the hardware with respect to such items as control logic, valve operation, instrumentation, thermal control, EGSE control, pressure integrity, outflow and tank capabilities, as well as servicing, off-loading and abort considerations. Requirements for functional tests are identified in end item design specifications and are performed at either ambient or the environmental exposure conditions.
- Environmental: This category of test will verify operation over the expected extremes of thermal, vacuum, vibration/acoustics, and electromagnetic environments. The intent of these tests is to verify the experiment design and operational, capabilities of critical subassemblies to properly function in the flight environment.
- Qualification: Qualification tests are formal, contractual demonstrations that the design, implementation and manufacturing methods have produced hardware at component, assembly, subsystem or system levels which conform to specification requirements. Test levels shall account for variations in hardware and environments and provide a factor of safety.
- Performance: These operating test verify that all systems, circuits and software are operating as required by design specifications and includes separate checks of all contingency, back-up, and off-nominal operational checks.
- Developmental: This category of testing is conducted to verify design concepts, assure compliance to performance requirements, and establish safe operating or performance limits/conditions for the equipment being evaluated. They are required when program risk is unacceptable to rely on undemonstrated configurations and where performance/design concerns cannot be deferred to the normal test flow for resolution. Breadboards, brassboards, structural models, and mock-ups are used in support of development testing.

Other Verification Methods - Other verification methods complement the full-up test approach provided above and will be used where appropriate to augment this primary method. Although test nominally provides the most credible proof of performance capability, judicious selection of the listed verification methods shall be made where cost effective.

Test and Verification Program Objectives - Objectives of the test and verification program are expanded upon below:

proceeding with the test. Upon completion of the test a post-test review will be held to close out the test and verify that all requirements of the test procedure have been met.

Verification and Ground Test Program Management Approach - The CONE ground test program will be project oriented with testing being accomplished at the contractor's manufacturing, test and laboratory sites. CONE project management has the overall responsibility of the ground test program at whatever facility is being utilized. Project functions participation necessary to this effort include engineering, manufacturing, test, quality, safety, software, logistics, training, and other technical support specialty areas. The basic verification management philosophy is to provide positive assurance that all of the specified requirements have been verified, and that the system can perform as designed. Key to managing the program verification activity is the planning effort performed by the project test management organization to organize, define, and delegate specific tasks and to monitor performance against the plan by providing a team effort to produce a quality product in accordance with cost and schedule.

Fabrication, Subassembly, and Assembly Test Requirements - These tests consist of in-line subassembly tests for the integration and testing of CONE at the subassembly level. The protoflight levels and durations for the tests will satisfy the verification requirements to be imposed. The CONE ground test program consists of those inspections and tests required to verify the integrity, performance, and functionality of the experiment subsystem and associated support subsystems before the system is integrated and includes the associated TA test program.

System Assembly and System Level Test Requirements - Systems integration testing will be performed at the experiment and support subsystems levels as the system is being assembled and integrated to verify interfacing compatibility and mechanical, fluid and electrical functionality of combined elements. As the experiment subsystem elements are being integrated to one another, component modules and LN2 storage tank will under go experiment subsystem proof pressure, LN2 functional characterization and integrated leak checks. As the support subsystem elements are being integrated to one another, testing will be accomplished that includes all electrical checkout. After the system level workmanship tests are complete a series of system level tests will be performed to check for proper function and responses between the major elements of the CONE flight hardware and software and includes compatibility and performance tests. A complete ground loading mission simulation followed by a flight mission simulation under a space environment condition will be conducted.

Software Test - Those events and activities associated with software test planning, conduct, and analysis at the product and system levels assure an error-free software product. Testing is used to demonstrate that system requirements are met and to identify coding errors and design flaws. The objectives of software testing are to verify that program specification requirements at both the Computer Software Configuration Item (CSCI) and system levels have been met and to ensure that development is complete prior to use in the on-orbit operational mission environment.

LN2 Storage Tank Test Article (TA) - The LN2 storage tank test article (TA) consists of the tank elements necessary to support development, functional and qualification testing of the assembled tank. In addition to the tank and its supports, interface lines to test valving and control interface for command and data handling will be provided. Due to the critical nature of the tank design to contain LN2 and operate successfully and in a safe manner while in the Orbiter payload bay this TA approach was baselined. Payload design and certification in the post-Challenger era, we believe makes a protoflight approach for a cryogenic storage tank very difficult. The TA will serve as an engineering development article, as well as a qualification article for tank certification. In-line testing during fabrication and assembly are followed with both functional and qualification tests. The tank will be designed with adequate margin so that it could serve as a ground test bed after all TA testing is complete assuming there is no good reason to cut apart the tank to perform an internal inspection. The tank will not yield at the applied burst level nor suffer excessive life degradation due to pressure or vibration cycling. After potentially destructive testing is accomplished post-test functional checks will be accomplished to verify nominal operation and to verify that no performance degradation was experienced. All components and elements that comprise the flight article LN2 storage tank design will be included in the TA. Three or more additional test instrumentation accelerometer and strain gage sensors will be a part of the configuration. Figure 9.1.2-1 shows the TA schematic and associated GSE support elements that will be required to aide in the test and checkout of tank internals.

Discussion of LN2 Storage Tank Protoflight Approach - Both IRAS and COBE flew protoflight LHe dewars and were launched from ELV's. Comparing CONE to these programs is not a good measure of how we should plan for CONE certification which has to be approved by NASA-JSC Safety. ELV vs. Orbiter are two different worlds where P/L certification is concerned. The better measure of CONE tank certification and how it should relate and use an existing program as a model is SHOOT. The SHOOT contains two identical flight dewars. Three dewars are being built for the program. Originally one tank was to have been a TA qualification unit. As the program progressed philosophy regarding this tank changed and it was converted into a flight spare. This was possible only because of the large safety factors and margins originally designed into the tank. It is questionable whether JCS Safety would allow this tank to fly. It is our recommendation (until further formal interchange with JSC safety can be accomplished) that CONE LN2 tank certification be supported by a TA. The difference in tank commodity mass (LN2 is 6.5 times heavier than LHe) also has to be considered in similarity of approaches and how we justify trying to sell a protoflight approach to JSC. Impact and phasing of this approach on the CONE Phase C/D schedule will require further assessment. Further assessment of an approach similar to SHOOT where the tank design has sufficient margin that the TA tank could be converted to the flight article after successfully completing the TA program is required. If a protoflight approach is acceptable to JSC safety, then the TA would be converted to a flight unit requiring the build of only a single LN2 storage tank. The final discriminator will be JSC safety acceptance of a proposed protoflight approach for the LN2 storage tank that would use the TA for flight. We propose back-up hardware to be available for assembly of a second tank if needed. This approach has the potential to reduce program risk while reducing cost based on a success oriented early test program of the tank that in effect would fly a protoflight tank by still performing a TA program between PDR and CDR and then using the TA for flight. We have baselined the more conservative approach of requiring a TA developmental and qualification unit and a second build of the flight tank.

TA In-Line Fabrication Test Flow - Figure 9.1.2-2 depicts the flow of in-line test during TA assembly prior to functional testing. Such test constitute developmental acceptance tests. Developmental TA acceptance tests are performed at all levels of assembly commencing with piece-part acceptance and proceeds through post manufacturing checkout to any formal testing required by the end-item specification to verify compliance with established criteria and acceptable go/no-go limits at the subsystem level to ensure proper fabrication and workmanship. TA subsystems will be subjected to prescribed simulated environments at levels defined for qualification use of hardware. Such tests include:

- Subassembly Proof Pressure Test - Subassemblies of the TA will be subjected to proof pressure acceptance testing at various stages of the fabrication and assembly process to verify pressure integrity. This acceptance test is a demonstration of the overall pressure integrity of various elements of the TA needed for pressure containment, as well as verifying workmanship quality at important stages in the assembly process.

- TA Subassembly LN2 Cold Shock - Subassemblies of the experiment subsystem will be subjected to LN2 cold shock acceptance testing at various stages of the fabrication and assembly process to verify unit compatibility with the intended test fluid. This acceptance test is a workmanship check and verification of subsystem integrity at the operating temperatures of the system prior to proceeding with further system installation/integration.

a. Provides verifications that the design yields the specified performance;

b. Provides confidence that fabrication defects, marginal design, marginal parts, and marginal components (if any exist) will be detected early in the test sequence by verifying hardware integrity before performing steps that would preclude efficient repair or replacement;

c. Establishes minimal risk that proceeding with subsequent program phases (ground and flight operations) will not uncover significant design inadequacies;

d. Performs survival verification that the elements of the system can survive the environments predicted to be encountered during transportation, handling, integration, ground processing, launch, and on-orbit;

e. Verifies compatibility and operational readiness that the system and all of its elements/subsystems, as-built and assembled, are compatible with each other and are capable of performing the mission functions;

f. Establishes a system characterization by providing the operating signature of the system through a combination of performance, calibration and functional data at component, subsystem, system, and combined segment levels which provide the basis for the acceptance and delivery of the system;

g. A significant one-g data base can be obtained by performing ground testing of the flight hardware to duplicate as closely as possible the on-orbit experiments which can be accomplished as part of functional or performance testing and can be integrated as part of flight hardware acceptance testing.

Verification Philosophy - The CONE Verification Program shall be primarily composed of development, qualification (design assurance) and acceptance testing relating to the various subcomponents, components, subsystems, and system. Every effort will be made to qualify hardware at the component level, in particular, to limit qualification to only differences imposed by CONE usage. Flight experimental payload qualification will use a protoflight approach to qualify the overall system.

Philosophy of Testing - The protoflight concept of testing will be used on the CONE program. Protoflight is the term used for the modified method of qualification testing defined in MIL-STD-1540B, Section 8. It is a method that limits exposure of items being tested to lower thermal and dynamic testing levels that would ordinarily be used for qualification. Its purpose is to permit the use of qualification test articles as flight hardware. All components, except those suitable for verification by similarity, shall be subjected to verification testing at the component level. All other verification testing will be accomplished at the highest level of assembly deemed practical. The following guidelines will be employed in the design of the testing:

a. Design margins for dynamic environments shall be the maximum predicted level (MPL) + 6.0 dB margin, whereas the protoflight test margins shall be reduced to MPL + 4.5 dB nominal (which includes the test tolerance of 1.5 dB).

b. Thermal design margins shall be MPL + 11 degrees C uncertainty factor and 10 degrees C margin, whereas the protoflight test margins shall be reduced to MPL +11 degrees C uncertainty and 5 degrees C margin. Where LN2 temperatures are the lower limits of exposure, no uncertainty or margin can be applied for testing purposes to further reduce the temperature environment.

c. All acceptance testing shall be conducted at MPL or minimum workmanship levels whichever is higher. Minimum workmanship levels are those levels necessary to detect defective workmanship. Where multiple flight articles are required, only one article shall be acceptance tested to protoflight test vibration cycling. After potentially destructive testing is accomplished post-test functional checks will be accomplished to verify nominal operation and to verify that no performance degradation was experienced. All components and elements that comprise the flight article LN2 storage tank design will be included in the TA. Three or more additional test instrumentation accelerometer and strain gage sensors will be a part of the configuration. Figure 9.1.2-1 shows the TA schematic and associated GSE support elements that will be required to aide in the test and checkout of tank internals.

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- Subassembly Proof Pressure Test - Subassemblies of the TA will be subjected to proof pressure acceptance testing at various stages of the fabrication and assembly process to verify pressure integrity. This acceptance test is a demonstration of the overall pressure integrity of various elements of the TA needed for pressure containment, as well as verifying workmanship quality at important stages in the assembly process.

- TA Subassembly LN2 Cold Shock - Subassemblies of the experiment subsystem will be subjected to LN2 cold shock acceptance testing at various stages of the fabrication and assembly process to verify unit compatibility with the intended test fluid. This acceptance test is a workmanship check and verification of subsystem integrity at the operating temperatures of the system prior to proceeding with further system installation/integration.

The pressure as a function of time will be recorded and monitored to determine rate of change and control accuracy. The storage tank will be in the normal vertical position during this test so that liquid is always being fed to the pump and the CHX .

• Instrumentation Operation - During the accomplishment of other storage tank functional checks all instrumentation will be monitored for proper sensor operation.

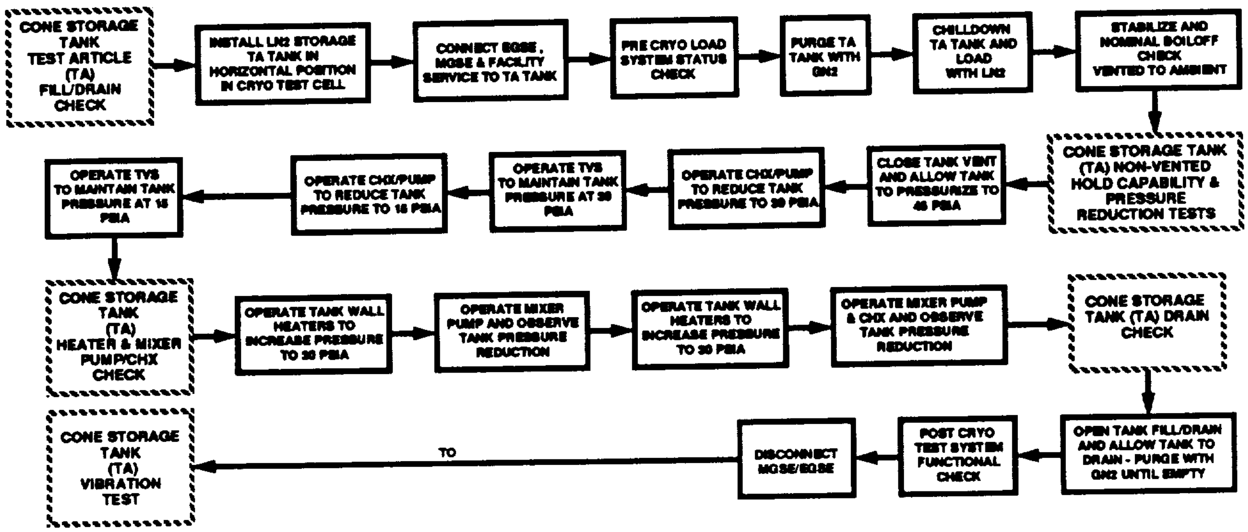

Figure 9.1.2-3 TA Verification Test Flow

TA Qualification Test Flow - TA Qualification tests are formal, contractual demonstrations that the design, implementation and manufacturing methods have produced hardware at component, assembly, subsystem or system levels which conform to specification requirements. Test levels shall account for variations in hardware and environments and provide a factor of safety. TA qualification tests (shown in Figure 9.1.2-4) include the following:

• TA Component Level Qualification Requirements - Qualification requirements for components that make up the LN2 storage tank TA assembly shall be contained in the individual component procurement specifications. Needs for qualification test articles and levels of qualification or delta qualification shall also be provided. Qualification needs shall be considered for the following TA procured elements:

1. Mixer pump	7. Manual service valves
2. Electrically operated outlet valves	8. Tank wall heaters
3. PV support straps	9. Pressure transducers
4. Temperature sensors	10. Point liquid level sensors
5. Continuous liquid level probe	11. Electrical connectors
6. VJ pump out and pressure relief	12. Tank wall heaters

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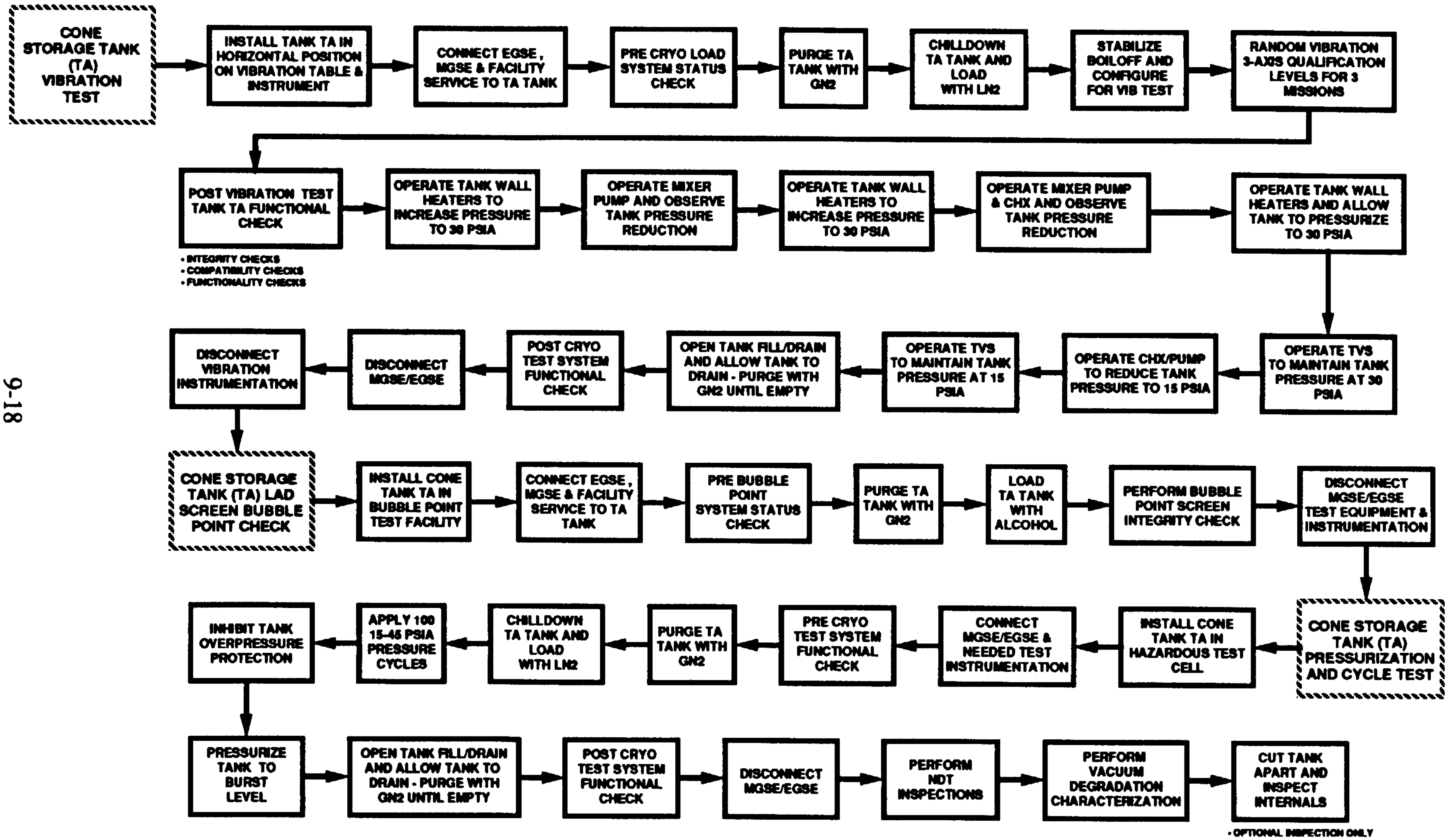


Figure 9.1.2-4 TA Qualification Test Flow

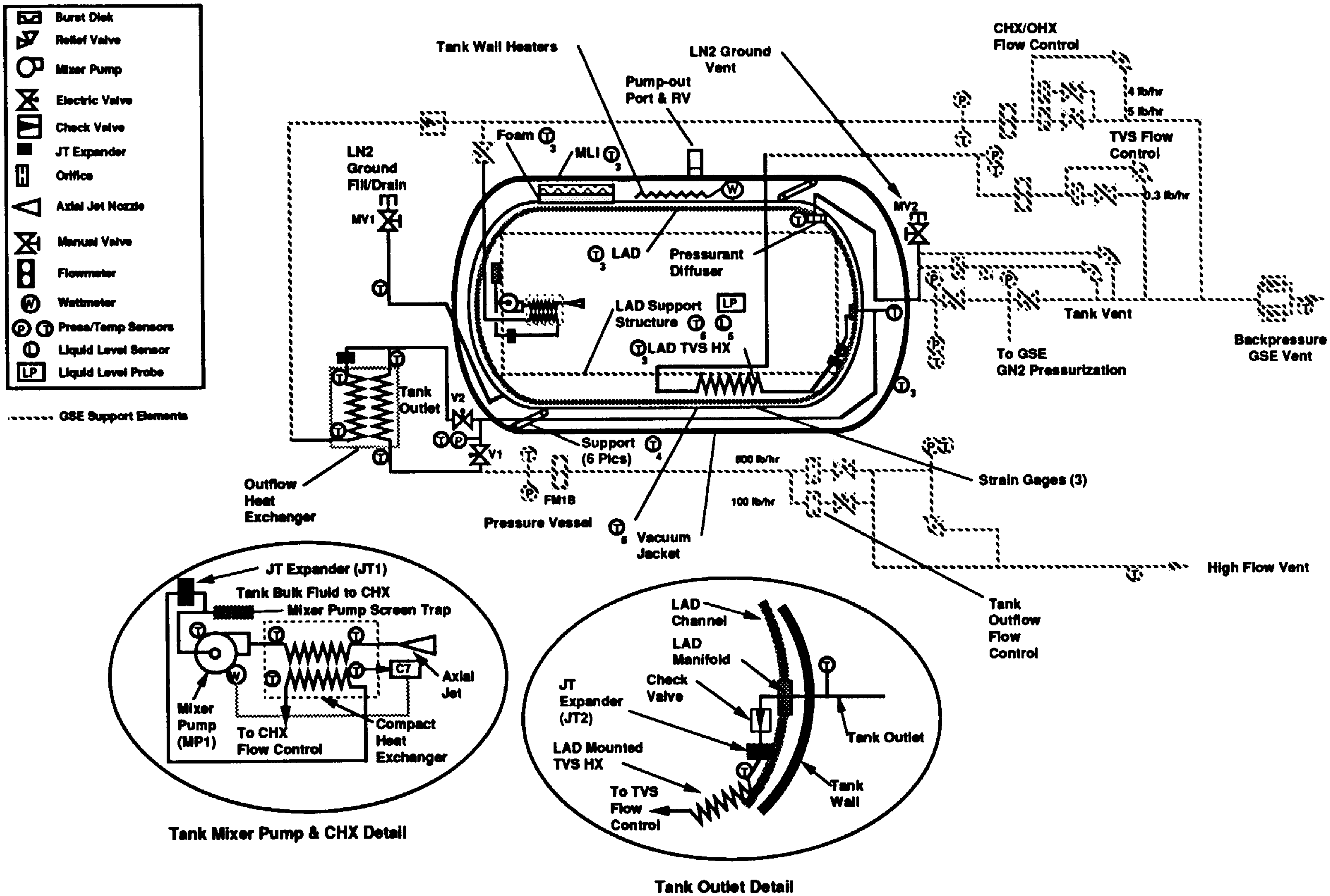


Figure 9.1.2-1 CONE LN2 Storage Tank Test Article (TA) Schematic

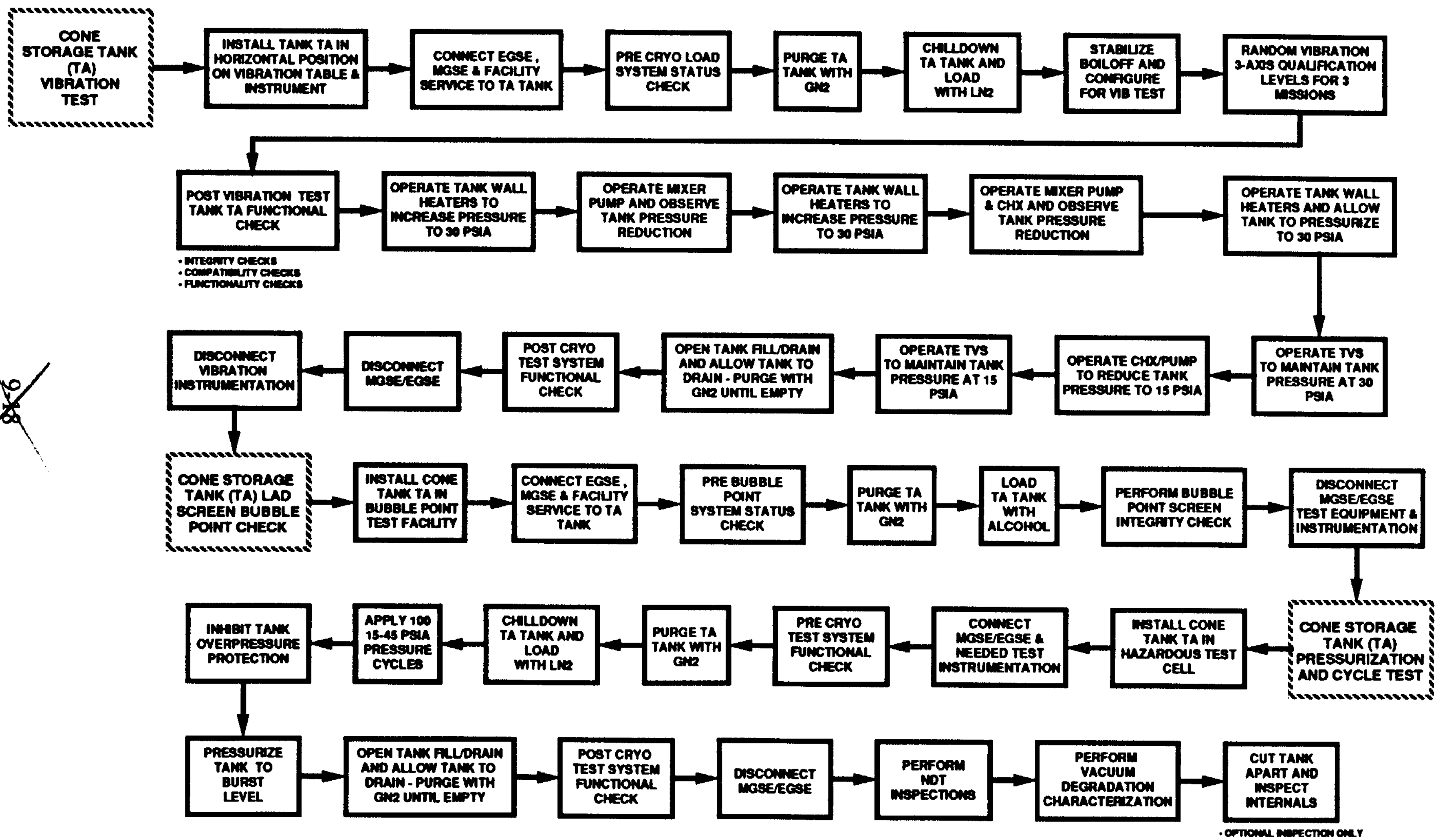


Figure 9.1.2-4 TA Qualification Test Flow

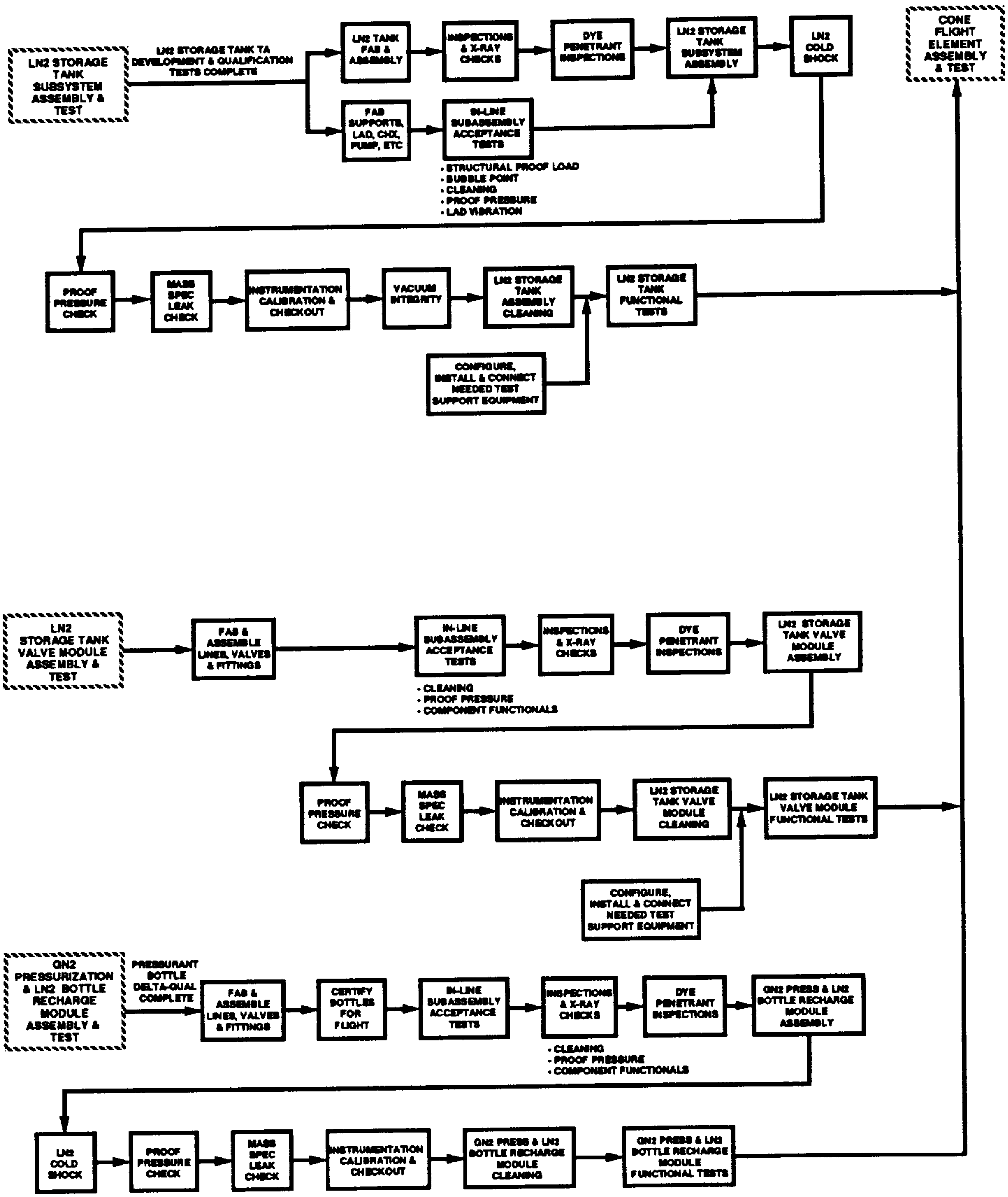


Figure 9.1.2-5 Experiment Subsystem In-Line Fabrication/Assembly Test Flow

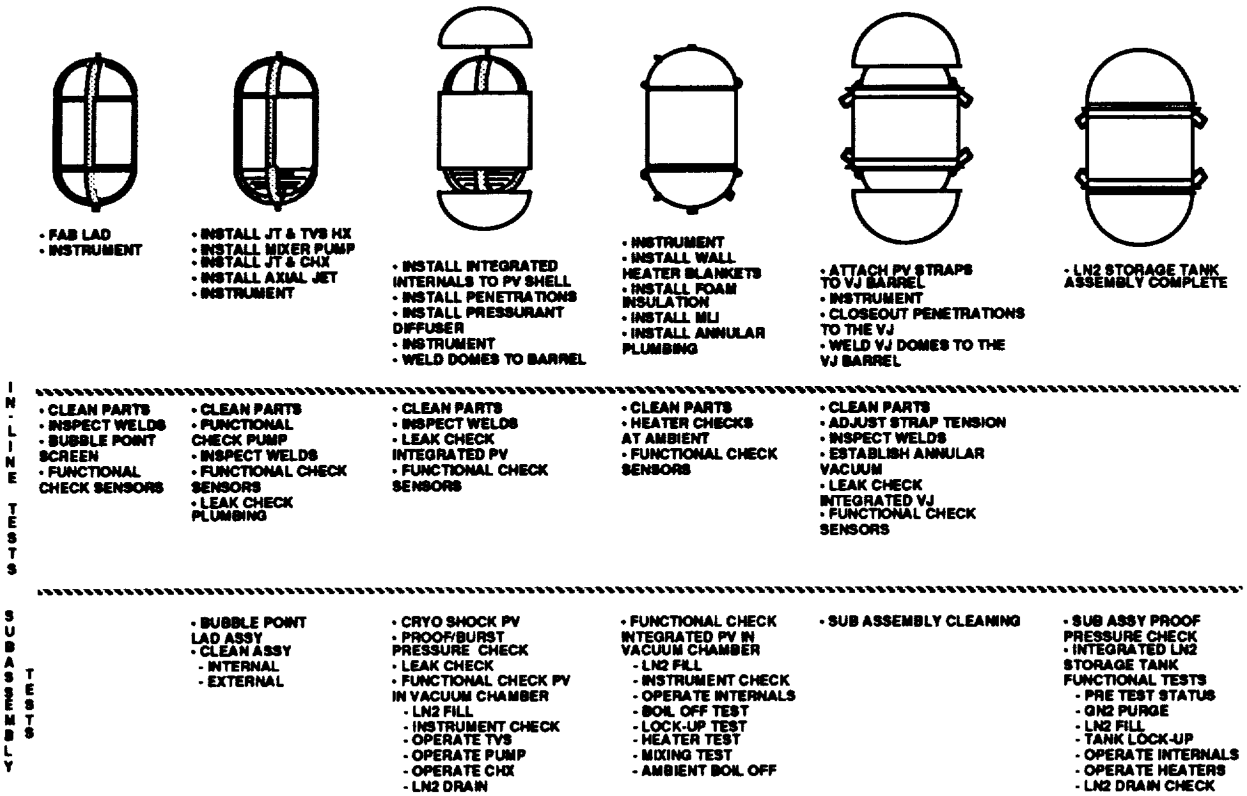


Figure 9.1.2-6 LN2 Storage Tank Fabrication and Test

• Systems Integration Testing - As the support subsystem elements are being integrated to one another testing will be accomplished that includes verification/checks for power allocation vs consumption, power distribution cable loss, power switching characteristics, ripple current measurements, power bus variation and stability, power profile performance, grounding, telemetry position, timing relationships, and telemetry values and modes with all combinations of formats, including rates, memory readout, frame sync, format ID and clock. All combinations of elements of downlink communications will be checked along with calibration of analog measurements, transducer operation, digital measurements verification for information content, command capability and interface operation which include tests for uplink error detection, correction and execution, redundancy management, anomaly response, fault protection and P/L safing (including experiment subsystem safing), plugs out verification, inertial properties, temperature control, sequence verification & validation and software integration. Tests will verify compatibility to the STS and the POCC.

<u>System Level Assembly and Acceptance Test Flow</u> - Other assembly testing (Figure 9.1.2-8) at both the component, subassembly, subsystem, and system level after the entire integration of the experiment and support subsystems is accomplished will be performed and will include the following types of checkout:

• Subsystem Integration - Such testing will verify grounding and isolation, bonding, interfacing, operating states, and selected functional capabilities. Each subsystem should have a minimum of 500 hours of operating time accumulated from all phases of the ground test program through and including pre-launch operations. Electrical/electronic flight hardware should be operated for a minimum of 300 hours prior to launch including subassembly, subsystem and system testing.

• LAD Subassembly Vibration for the TA - The completed LAD subassembly for the TA will be subjected to a random and transient vibration test at ambient conditions designed to demonstrate capability to withstand the vibration environment imposed during flight plus a qualification design margin of safety.

• LN2 Storage Tank TA Vibration - The completed LN2 storage tank TA will be subjected to a random and transient vibration test with the tank loaded with LN2. This test is designed to demonstrate capability to withstand the vibration environment imposed during flight plus an acceptance design margin of safety and to verify workmanship quality. This qualification test will verify the structural/functional integrity and life of the LN2 storage tank TA for the expected random and transient vibration flight environments. Vibration testing shall be performed with the LN2 storage tank TA mounted in a vibration fixture oriented in the launch attitude in the identical manner as for flight usage. This requires that the mounting hardware for the tank be fixtured to simulate the attachment to the HH-M carrier. The required vibration criteria shall be applied to the test item simultaneously along each of the three orthogonal axes. This test will be conducted at standard pressure and temperature conditions along with the following:

- Random Vibration: The random vibration environment will be derived in the next CONE program phase and will consider mechanical input from the HH-M carrier, as well as direct acoustic excitation. Testing will be conducted in the x, y, and z axes for the equivalent of 3 launches.
- Transient Vibration: The transient environment will be derived analytically based on a dynamic loads analysis so that sufficient transients in each axis will be inputted to qualify the tank design.

Available instrumentation shall be monitored to verify that proper vibration exposure levels were attained. Accelerometers and strain gages will be used as test instrumentation. Recorded data shall be analyzed for verification of proper subassembly/subsystem post test functional operation.

The LN2 storage tank TA shall function satisfactorily (no abnormal performance) after the vibration test and shall show no visible indications of structural damage, degradation or permanent set as a result of the vibration test. A bubble point check of the tested tank shall verify LAD integrity.

• TA Pressure Cycle and Burst Test - The completed LN2 storage tank TA will be subjected to a pressure cycle and burst test at cryogenic conditions designed to demonstrate capability to withstand the expected pressure fatigue from a three mission life plus a qualification design margin of safety. After the pressure cycle test is complete a no yield burst pressure will be applied to the pressure vessel.

• Vacuum Degradation Characterization - An off-nominal performance characterization of the TA tank will be performed to determine worst case venting potential from the tank should a failure of the vacuum jacket occur.

Experiment Subsystem In-line Fabrication/Assembly Test Flow - The flow chart, in Figure 9.1.2-5, of in-line subassembly tests provides an overview for the integration and testing of CONE at the subassembly level. The protoflight levels and durations for the tests will satisfy the verification requirements to be imposed. The CONE ground test program consists of those inspections and tests required to verify the integrity, performance, and functionality of the experiment subsystem and associated support subsystems before the system is integrated. Specific experiment subsystem verification consists of the following types of tests:

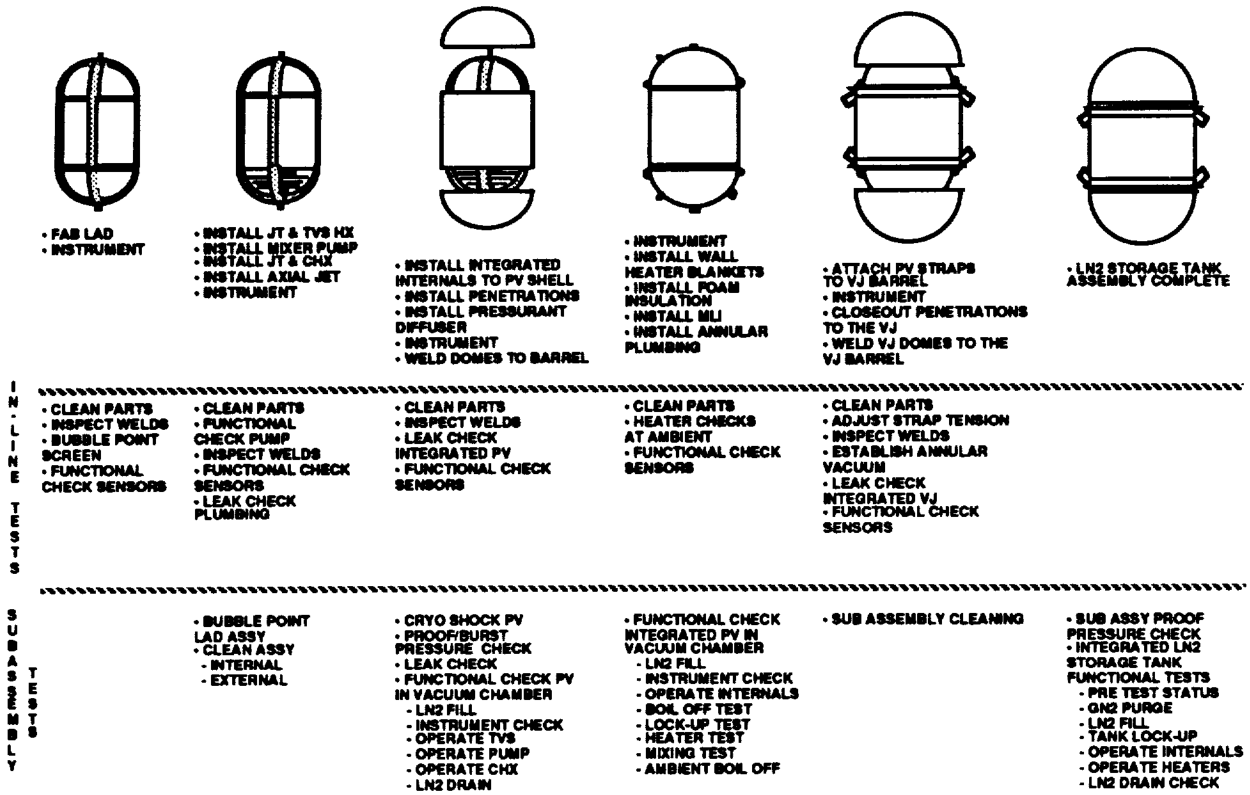


Figure 9.1.2-6 LN2 Storage Tank Fabrication and Test

• Systems Integration Testing - As the support subsystem elements are being integrated to one another testing will be accomplished that includes verification/checks for power allocation vs consumption, power distribution cable loss, power switching characteristics, ripple current measurements, power bus variation and stability, power profile performance, grounding, telemetry position, timing relationships, and telemetry values and modes with all combinations of formats, including rates, memory readout, frame sync, format ID and clock. All combinations of elements of downlink communications will be checked along with calibration of analog measurements, transducer operation, digital measurements verification for information content, command capability and interface operation which include tests for uplink error detection, correction and execution, redundancy management, anomaly response, fault protection and P/L safing (including experiment subsystem safing), plugs out verification, inertial properties, temperature control, sequence verification & validation and software integration. Tests will verify compatibility to the STS and the POCC.

<u>System Level Assembly and Acceptance Test Flow</u> - Other assembly testing (Figure 9.1.2-8) at both the component, subassembly, subsystem, and system level after the entire integration of the experiment and support subsystems is accomplished will be performed and will include the following types of checkout:

• Subsystem Integration - Such testing will verify grounding and isolation, bonding, interfacing, operating states, and selected functional capabilities. Each subsystem should have a minimum of 500 hours of operating time accumulated from all phases of the ground test program through and including pre-launch operations. Electrical/electronic flight hardware should be operated for a minimum of 300 hours prior to launch including subassembly, subsystem and system testing.

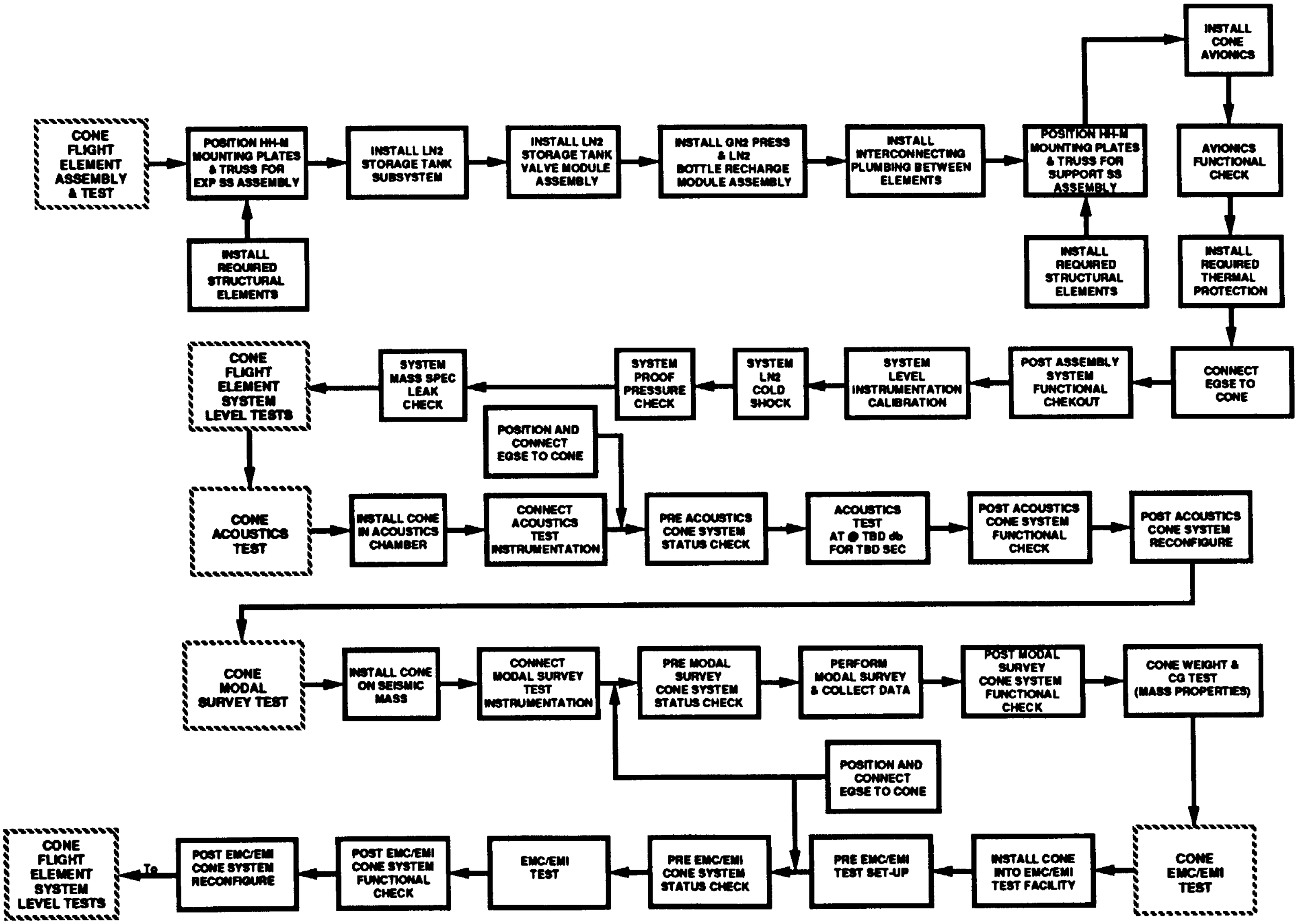


Figure 9.1.2-8 System Level Assembly and Acceptance Test Flow

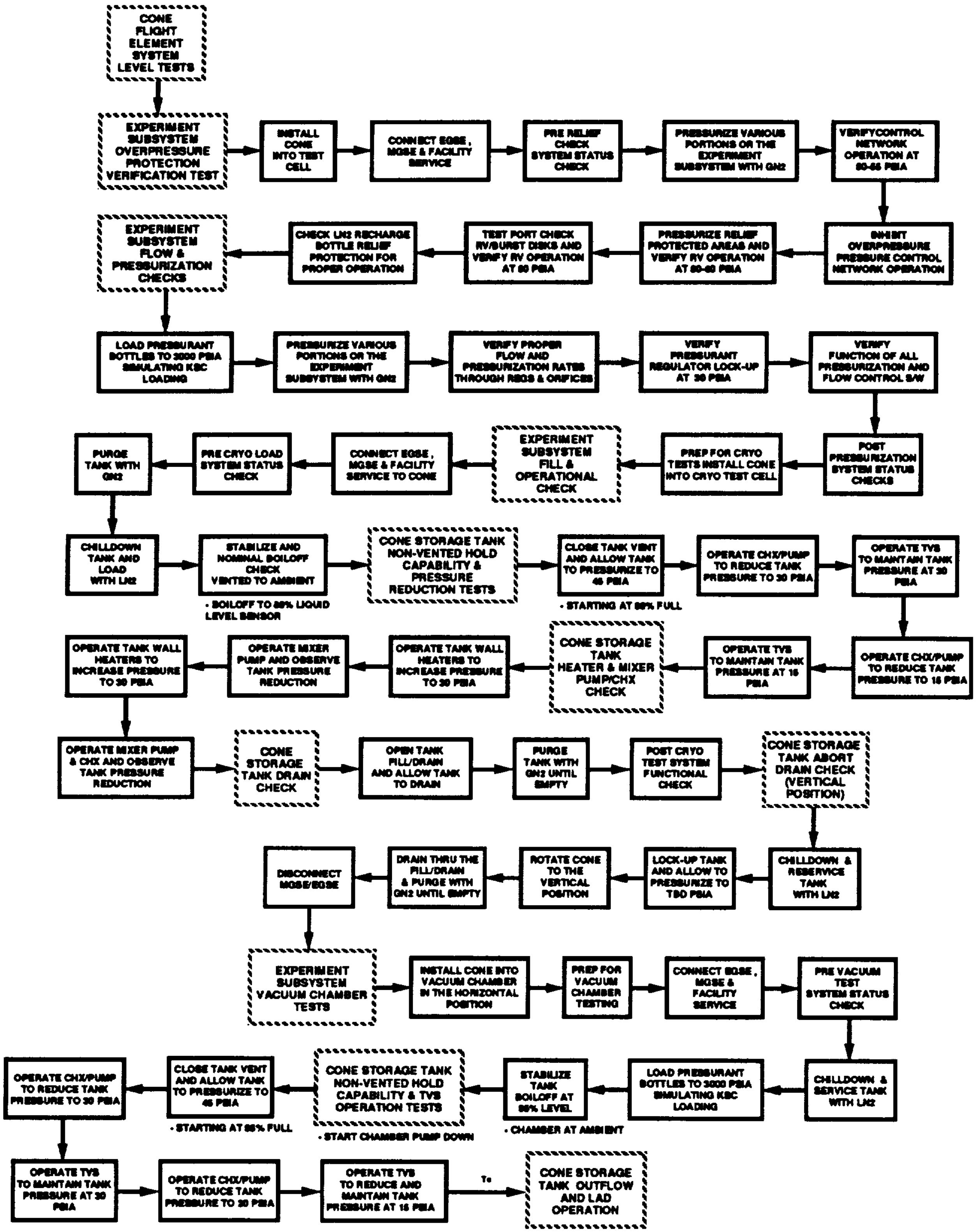


Figure 9.1.2-9 System Level Test Flow

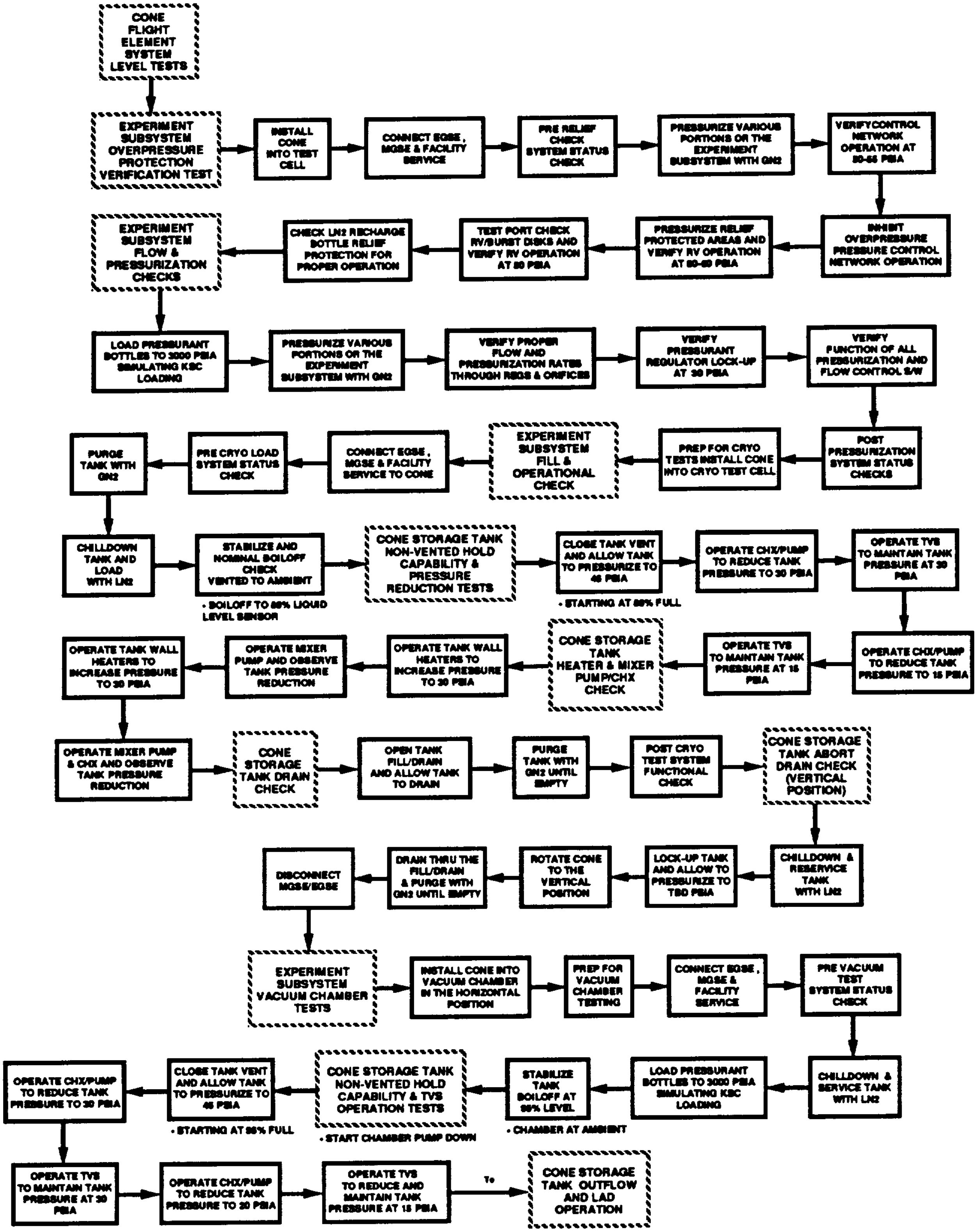


Figure 9.1.2-9 System Level Test Flow

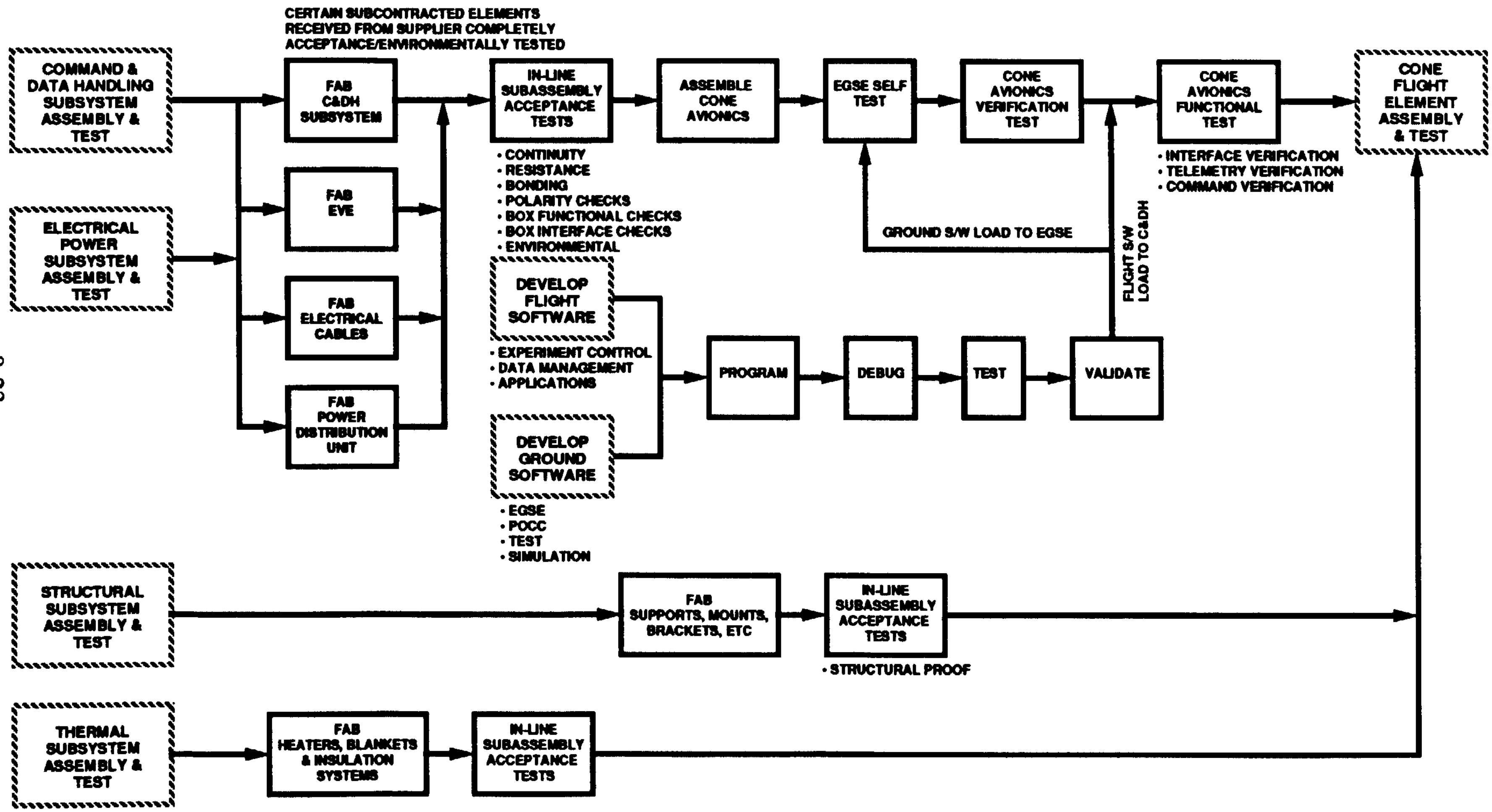


Figure 9.1.2-7 Support Subsystem In-Line Fabrication/Assembly Test Flow

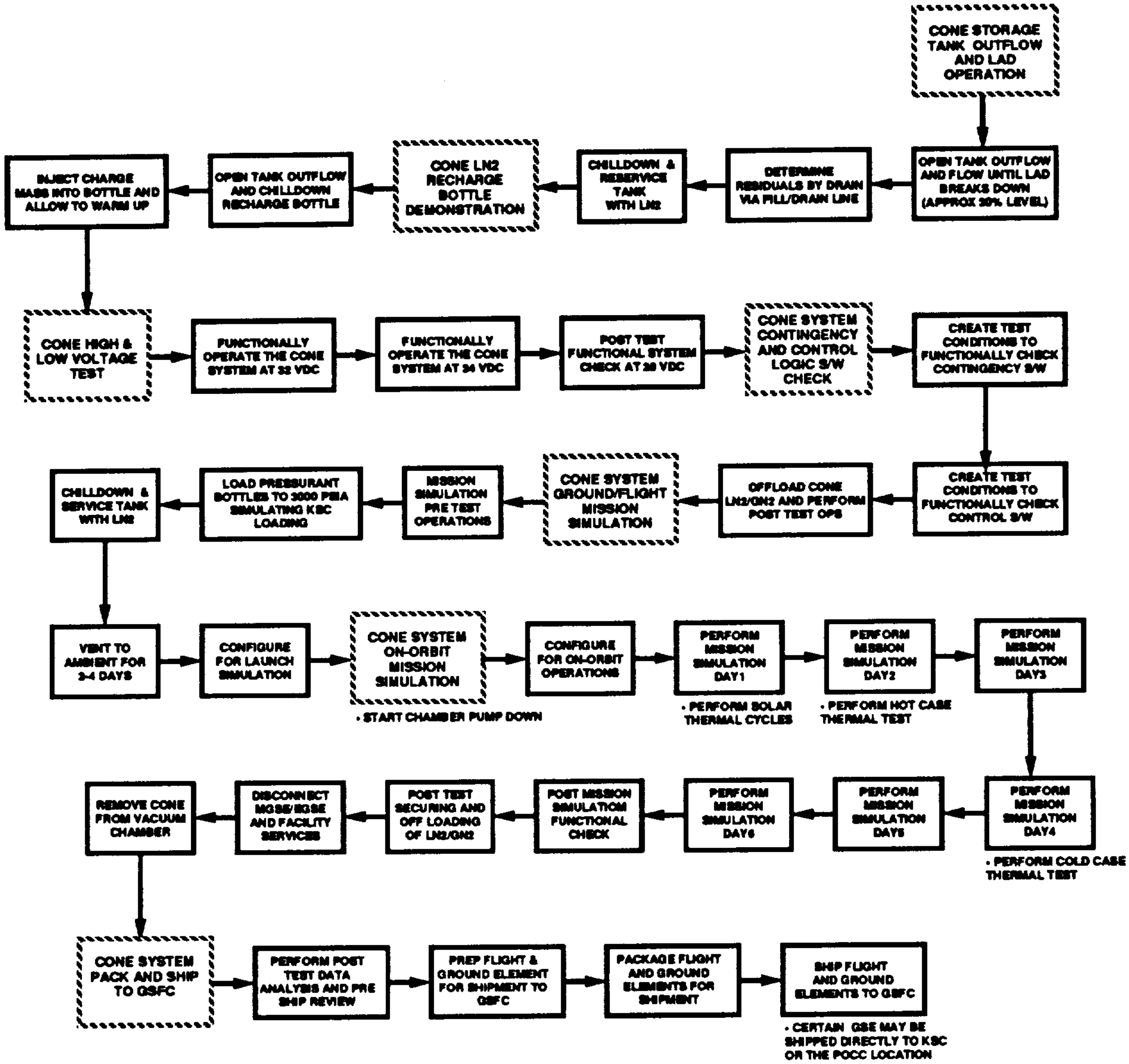


Figure 9.1.2-9 System Level Test Flow (Concluded)

down. Simulation of the on-orbit position requires that the GSE support fixture be rotated to the vertical position. Close out of the chamber is accomplished so that pump down can proceed and on-orbit simulated operations can be started. The system is powered up four hours later and the simulation of the 5-6 day mission is initiated. Throughout this test data from downlink channels will be recorded at the EGSE console. Test instrumentation will also be recorded. This data will form the basis for the ground data base for math model correlation and to verify predicted to actual performance. OBC C&DH software will be validated over the six day span simulating the actual mission sequence of events and timing. All subsystems shall function as an integrated unit to accomplish the sequential operations of the experiment. Proper experiment and support subsystem performance shall be demonstrated.

The integrated CONE flight system mounted to the support and rotational GSE fixture will be installed in the flight attitude in the thermal vacuum chamber equipped with radiant heaters and a cold wall for achieving the required temperatures as shown in Figure 9.1.2-10. A simulated scenario for nominal flight functions will be performed to verify system operation. During this time the chamber thermal environment will be adjusted to simulate the acceptance and hot/cold soak levels and durations for all required conditions.

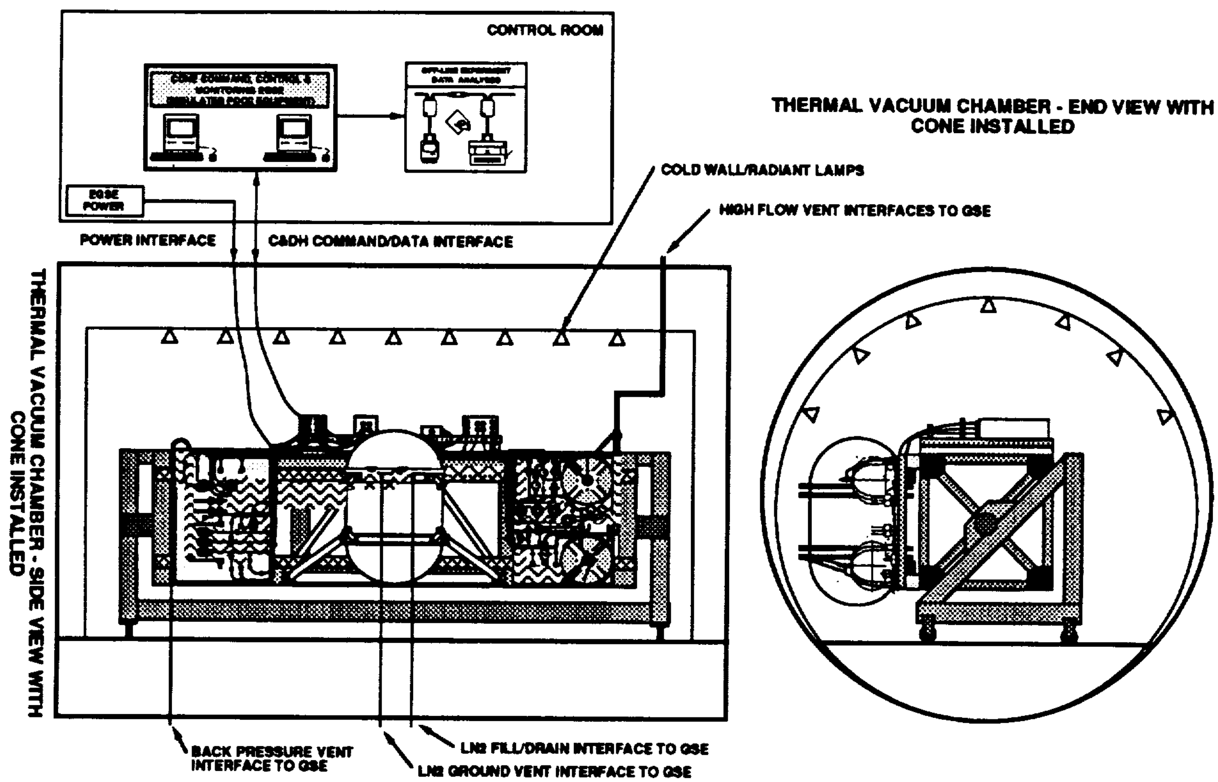


Figure 9.1.2-10 Test Setup for the Thermal Vacuum Chamber Mission Simulation

<u>S/W Development Life Cycle and the Testing Process</u> - Testing, both informal and formal, is the process that demonstrates the software's ability to meet system functional and performance requirements. Informal testing as part of the software development effort provides early visibility into Computer Software Configuration Item (CSCI) design, intra CSCI capability, and local inter CSCI performance that will help in determining the overall testability of the CSCI, as well as the feasibility of various test approaches. Informal test provide an indication of system readiness prior to formal testing. Two major areas of formal software testing include product and system. Product testing

ensures that CSCI requirements have been satisfied so that they can be integrated with the system hardware and tested at the system level where hardware and software interaction and compatibility are demonstrated. The process of software testing requires planning, test conduct, test support, anomaly resolution, error correction and retest activities and is divided into the following elements:

- Informal Software Test - Informal testing occurs during the Computer Program Test & Evaluation (CPT&E) phase. During this phase requirements are analyzed and Computer Program Components (CPCs) are identified, incrementally coded, tested and integrated. A historical record of these activities is documented and maintained in Unit Development Folders (UDF) and consists of individual S/W component test and string tests where two or more related S/W components are tested for interface and interaction performance.

- Formal Software Test - Product and system level testing comprise the two major levels of formal software testing. Product testing is CSCI qualification testing and ensures that specification requirements have been satisfied. Qualified CSCIs are then integrated and system tested. System testing not only ensures that specification requirements are satisfied, but that all functions and operations can be achieved.

Open Test Program Issues Deferred to the Follow-On Phase C/D - Certain testing contributes to the data package that supports payload certification for flight on the Orbiter. Since no formal interchange occurred during this phase with GSFC, JSC and KSC a conservative full-up testing approach has been baselined with the qualification that several areas need to be revisited as so as formal agreements are implemented with these centers. A brief discussion of each follows:

- LN2 Storage Tank TA - The need for a TA is driven by the success in formulating a protoflight approach for the tank based on large design margins and a comprehensive test program that provides enough data to support such an approach. Other development, fabrication and assembly needs should also be considered, as well as schedule impacts of a TA and cost implications to the program.

- Modal Survey Need - How some of the structural design and testing requirements are met with regard to dynamic characterization for a payload such as CONE that is spread out over various mounting plates and attachment structures remains an open issue that will require coordination with the GSFC HH-M Project Office. Designing the system for as high a fundamental frequency as possible is a goal that will have to be meshed with the mission and experimental needs of the program.

- Deferral of Testing - Certain component and in-line testing can be deferred and accomplished at the system level when enough confidence exists that such postponement will not compromise the system and add unacceptable cost, schedule or system performance risk to the program. Much uncertainty in component characterization and use with cryogens and operation in the space environment will tend to a more conservative and therefore a more costly approach.

- Test/Analytical Mix - Analysis can play an important part in the CONE verification program to support test effort, as well as demonstrating sufficient margin so that testing may be eliminated. Previous usage, heritage and design confidence in the listed areas will all contribute to achieving the proper mix of test and verification analysis.

- Design/Mission Issue Resolution - Various open design issues remain open that drive test requirements how the system will be tested. Until these are resolved and a more definitized baseline can be established in the follow-on phase C/D, best engineering judgement was used to approach the verification process and how the SDR baselined design would be tested.

9.2 Ground Processing

Ground processing commences with CONE flight hardware and associated GSE transport to GSFC where integration and testing with the HH-M carrier takes place, and ends with post-mission hardware deintegration from the carrier and transport of hardware to LeRC. Between these events pre-mission integration to the Orbiter occurs, as well as, the on-orbit mission.

CONE Transportation Approach For Flight Integration to the HH-M Truss - CONE will be transported to GSFC after Pre Ship Review (PSR) completion via an airride environmentally conditioned van from the CONE manufacturing facility to processing at GSFC where it will be integrated to the flight HH-M truss and is then ready for shipment to KSC. This flow includes the following:

- During final assembly, the CONE flight element will be integrated to the the support and rotational GSE dolly. The integrated equipment, in this configuration, can under go system level testing as a unit and will be transported on this dolly for convenience, safety, and program cost effectiveness.

- After the pre-ship review, the dolly-mounted CONE will be installed into an enclosed air ride van and transported over the road to GSFC where the CONE equipment will be inspected and prepared for flight HH-M truss integration. Required GSE will also be shipped in the same van.

- The CONE flight element equipment will then be removed from the GSE dolly and installed to the flight truss where mounting and interfacing to the HH-M avionics will take place.

- Standard P/L interface testing will take place after which the integrated unit will be ready for transport to KSC. The following tests will be performed at GSFC following integration of the CONE payload onto the HH-M flight truss:

    1. Interface testing for power, command and data compatibility
    2. System functional testing to confirm proper operation of integrated payloads and the absence of interference
    3. EMC testing of the complete payload to confirm compliance with STS EMI requirements may be accomplished
    4. Acoustic testing of the integrated HH-M carrier and all of the attached payloads may be performed
    5. CONE contractor support is required at these tests

CONE Transportation Approach for Flight Integration to the HH-M Support at KSC - CONE is transported from GSFC to KSC via an airride environmentally conditioned van to KSC for processing at KSC where the final integration to the flight HH-M keel fitting support structure is made. This flow includes the following:

- After final integration of the CONE flight element to the HH-M flight truss, the integrated unit is interface tested and readied for shipment to KSC.

- After a pre-ship review, the truss mounted CONE will be installed into a GSFC provided shipping container and transported over the road to the KSC facility where the CONE equipment and truss will be inspected and prepared for flight HH-M support structure integration.

- Standard P/L interface testing will take place after which the completely integrated CONE P/L is ready for transport to the KSC Vertical Processing Facility (VPF) where it will be integrated with other P/L's that will be vertically processed. Activities at KSC include:

- Integration of the combined HH-M payload into the orbiter is a NASA responsibility

- Functional tests to ascertain CONE health, launch readiness, and to verify interfaces to the orbiter aft flight deck switch panel will be performed with contractor support

- GN2/LN2 servicing and pre-launch monitoring/configuration operations will be performed/supported by the CONE contractor

After final carrier mate, the flow at KSC to and through the Vertical Processing Facility (VPF) continues on with final vertical installation into the Orbiter cargo bay in the Payload Changeout Room (PCR) at Pad 39. This flow includes the following:

• After final integration of the CONE flight element, HH-M flight truss integration to the support structure, and final interface testing, the completed P/L is readied for transport to the VPF.

• After a move review, the CONE/HH-M will be installed into a KSC provided transport container and transported over the road to the VPF.

• At the VPF, the P/L will be rotated to the vertical position and installed into the vertical payload processing fixture where it is integrated with other vertically processed payloads. Any further interface testing would be accomplished.

• The vertically assembled P/L train is then installed into the vertically oriented payload cannister and transported to the launch facility at Pad 39.

• Here the payloads are hoisted into the PCR where installation into the Orbiter cargo bay is accomplished.

Figure 9.2-1 provides a brief description of the top-level CONE tasks at KSC and the scheduling of these events for a typical 15 week flow which include the following five major task activities:

• Task 1.0 Post Delivery Operations - Post delivery operations will include the delivery of CONE hardware (including HH-M structure and associated MGSE/EGSE) to a designate PPF/HPF at the Kennedy Space Center, unloading hardware and performing receiving inspections.

• Task 2.0 Assembly And Integration - During this phase of operations, all CONE hardware are staged and the two piece CONE/HH-M assemblies will be built-up to its launch configuration. Upon completion of assembly, a post assembly & integration closeout will be performed.

• Task 3.0 Test And Checkout - CONE hardware and associated MGSE/EGSE are configured to support functional checkout and optional hazardous pressure systems test. If hazardous testing becomes a requirement, the Payload Hazardous Servicing Facility (PHSF), located within the KSC industrial area, can serve as both PPF & HPF facilities.

• Task 4.0 Vertical Payload Integration & CITE Testing - Co-manifesting of CONE hardware with the primary payload will occur at the VPF/Vertical Integration-CITE stand. If required, a simulated NSTS interface verification test will be performed following CONE integration with the vertical payload manifest. Optional LN2/GN2 servicing may be performed at this time. The integrated payload is then placed into a vertical MMSE canister/transporter and driven to the base of the RSS at Pad 39 A/B. The payload is then installed with in the Orbiter payload bay via RSS PCR crane and PGHM operations.

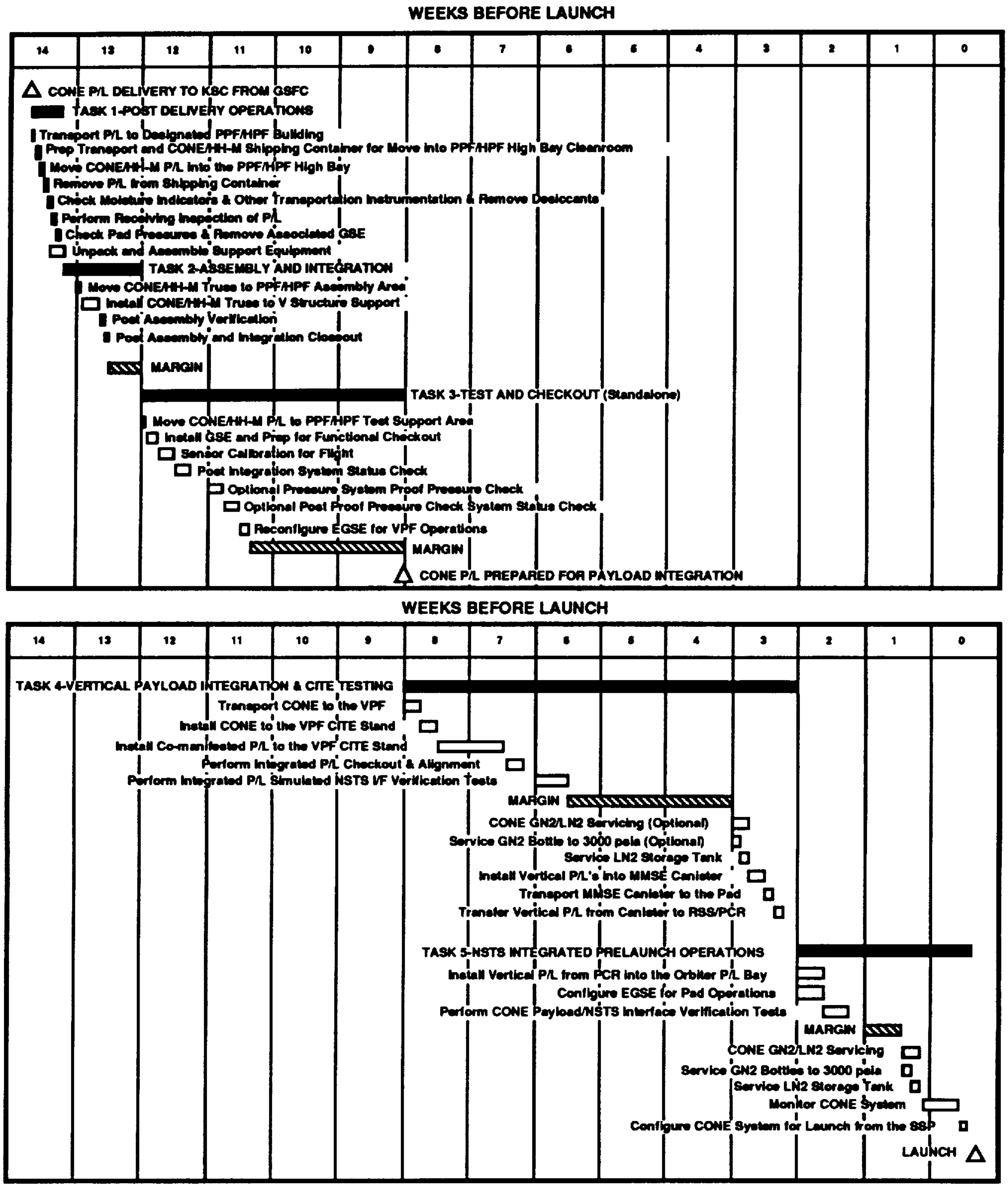


Figure 9.2-1 CONE Payload KSC Processing Timeline

• Task 5.0 NSTS Integrated Prelaunch Operations - Following completion of physical and functional payload/NSTS interface mate operations, a vehicle/payload interface verification test is performed. The remaining ground process operations are driven by NSTS process requirements. End-to-end communications testing will be performed at the Pad to verify mission communication. Optional CONE LN2/GN2 fill operations or topping off will be performed prior to payload bay closeout for launch. If LN2 top off is anticipated at the Pad, it is recommended that LN2 fill be performed at this time.

Figure 9.2-2 shows the flow at KSC and through the VPF and continuing on with final vertical installation into the Orbiter Cargo Bay in the Payload Changeout Room (PCR) at LC39. After final integration of the CONE flight element and HH-M flight truss, integration to the support structure, and final interface testing, the completed payload is readied for transport to the VPF. After a move review, the Payload will be rotated to the vertical position and installed into a KSC provided transport container and transported over the road to the VPF. At the VPF, the payload will be rotated to the vertical position and installed into the vertical payload processing fixture where it is integrated with other vertically processed payloads. Any further integration testing would then be accomplished. The vertically assembled payload train is then installed into the vertically oriented payload cannister and transported to the launch facility at LC39. The payloads are then hoisted into the PCR where installation into the Orbiter cargo Bay is accomplished.

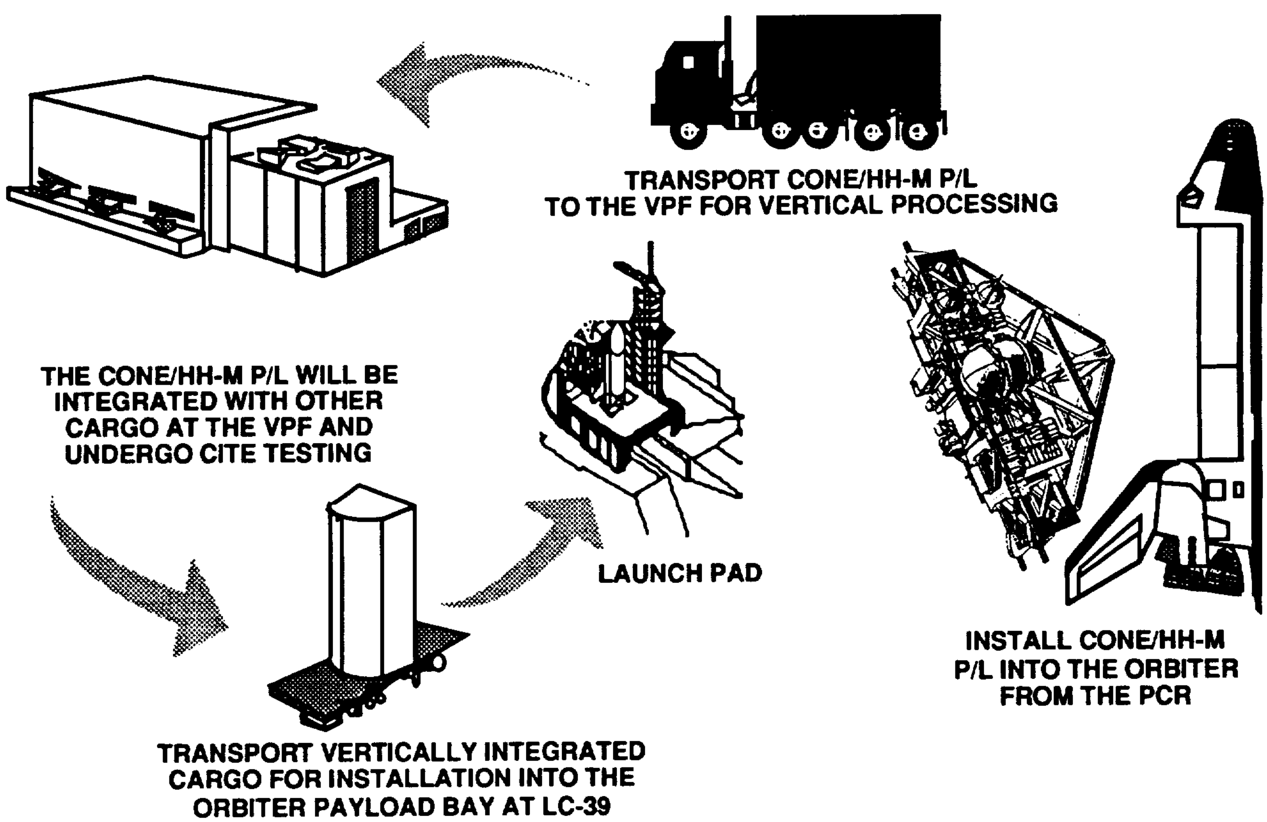
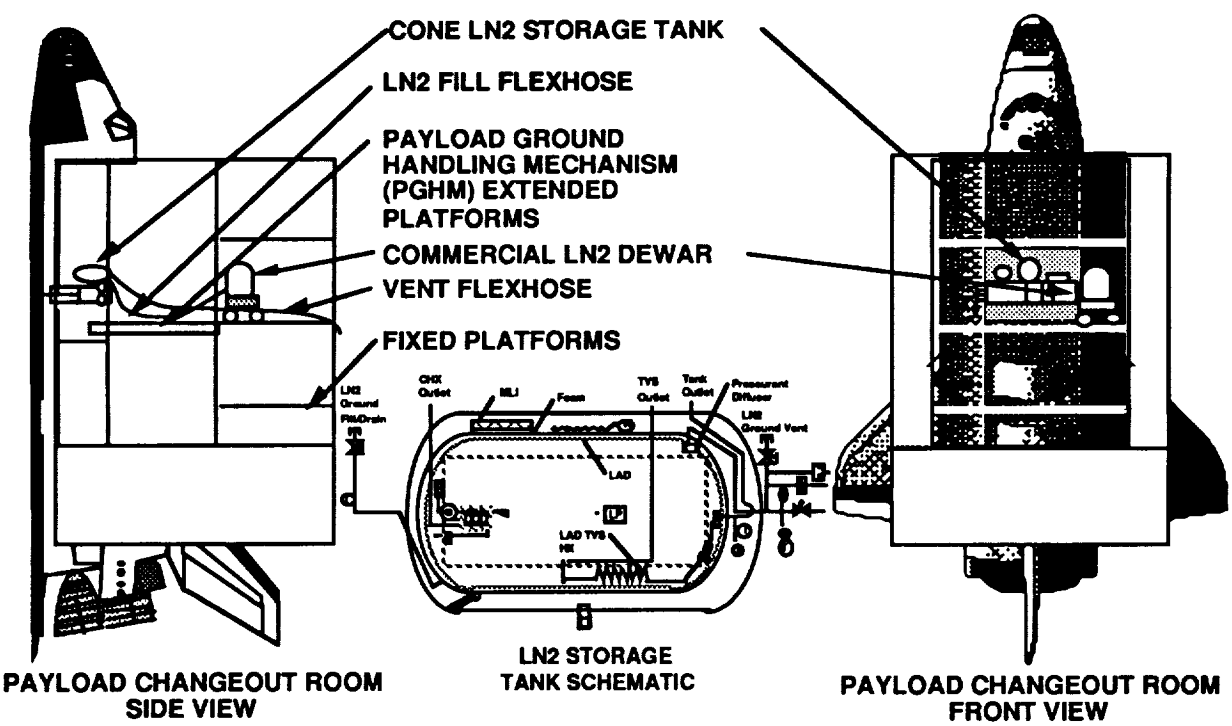


Figure 9.2-2 CONE/HH-M Payload Processing Flow at KSC after Carrier Mate

CONE Pad 39 Servicing, Monitoring, and Launch Configuration Approach - After the CONE P/L has been installed into the Orbiter Cargo Bay and any needed interface testing has been accomplished, final servicing operations can begin.

First, the GN2 pressurant tanks will be taken to a flight pressure of 20700 kN/m^2 (3000 psig). This operation could take place earlier in the processing and the time will be determined by KSC. Since working pressure is less than 50% of design burst, a safety factor greater than two is being maintained for this operation. KSC will determine restrictions that may be placed around the P/L after the bottles are serviced. GSE required for this operation consists of a regulation panel (which exists in the PCR facility) and a flex hose with restraints interfacing the regulated GN2 to the flight bottle servicing port. Bottles can be serviced in parallel to limit the time of the operation.

The LN2 storage tank will be serviced as close to launch as possible which will be determined by KSC Planning. Seven days prior to launch is our current preferred KSC servicing time, since we desire the longest ground hold time (boiloff to 85%) prior to needing topoff. This allows CONE to accommodate a launch slip of at least two-three weeks. Accomplishing the LN2 servicing in eight hours is an operational goal, including time for boiloff stabilization so that the ground vent can be disconnected. A commercial portable dewar/dewars made available by KSC that has internal pressurization provides an inexpensive and simple GSE approach for loading the storage tank with an insulated flex hose for fill and vent needs. The dewar/dewars will be located on a fixed level in the PCR based on where the CONE is manifested in the cargo bay. Access to the CONE is provided by extendable PGHM platforms. The storage tank GN2/LN2 vent effluent can be routed to a suitable location outside the PCR. The entire fill process is a manual operation and power-up of the CONE is not required. Figure 9.2-3 shows the LN2 ground servicing approach at Pad 39.



LN2 TANK PLUMBING WILL INCORPORATE A LIQUID SEEKS ITS OWN LEVEL FEATURE FOR IMPROVED DESIGN SAFETY

Figure 9.2-3 LN2 Storage Tank Servicing Approach at the LC39 PCR

After boiloff stabilization and securing of the ground vent, the flight vent valves are opened from the SSP and the tank is vented into the bay until just prior to launch. Approximately 24 hours before launch, the ground crew sets cabin switches for launch. At this time, the flight vent valves are closed for launch and the TVS will be opened from an SSP switch.

Ground Monitoring Options After LN2 Servicing - After the CONE has been serviced with LN2, periodic monitoring will have to be accomplished to status important P/L data so that nominal performance can be verified and to commit to configuring for launch.

The most straight forward (and also probably the most costly) technique to meeting this need is the T-0 umbilical approach. At any time the P/L can be powered up from ground power and the system can be statused. Inadvertent commanding issues have to be addressed for this option. Also a T-0 umbilical is not an optional Hitchhiker service per the HH CARS. Data would be fed into a cable link with the T-0 umbilical which will then be routed to a KSC EGSE location. Ground power could be used to power up CONE whenever monitoring is required or the payload could be powered via normal orbiter power up.

We have baselined a monitoring approach that provides for periodic HH-M power-up from the SSP and then having KSC provide CONE data routed to the KSC EGSE location or to the Launch Processing System (LPS) P/L console in the Launch Control Center (LCC) by a data strip out from either the PDI or the GPC. The payload would have to be powered via the normal Orbiter power up.

Post Landing Operations - The primary objectives of the CONE post landing operations are to determine the post mission condition of all CONE hardware, perform any required deservicing and to prepare the hardware for return to the design center designated location. The following provides a brief description of the CONE post landing tasks at KSC:

• Task 1.0 Integrated Post Landing Operations - The Orbiter primary landing site will either be DFRF as it is now, or the KSC SLF. After landing, the Orbiter and CONE will be safed while on the landing strip and prepared for return to the OPF. In the case of a KSC landing, this will occur within 4 hours of touchdown. For a DFRF landing, the return trip includes preparation for ferry flight on the SCA, Orbiter/SCA mate, ferry flight, Orbiter/SCA demate at KSC and tow to OPF. Once inside the OPF, NSTS post landing operations are continued with additional CONE safing and hardware removal from the payload bay.

• Task 2.0 Post Flight Operations - The MMSE payload transporter will be used to deliver the returned payload manifest from the OPF to the O&C building for payload deintegration and preparation for transport to the designated PPF/HPF for post flight processing. Within the PPF/HPF, the CONE will be placed in it's standalone work station and post flight inspection & optional functional testing will be performed. The CONE/HH-M assembly will be deintegrated to the extent required for transportation to the design center site. Upon completion of CONE packaging for shipment, CONE and it's associated MGSE and EGSE will be transported to Denver/LeRC.

9.3 Flight On-Orbit Mission Operations

The CONE on-orbit mission was developed so that the experiments and demonstrations could be accomplished on a nominal seven day Orbiter mission. A mission timeline previously shown in Figure 6.2-1 was assembled to accommodate all of the tests within this time constraint while allowing for periods of system operations holds to provide for coordination with the crew and other operations that may impact the flow of desired CONE operations. The total experiment time required is a little less than 6 days. Six days are shown to allow for other payload's operations that would prohibit CONE operation. Tests are arranged into six groups with the first three occurring at the high fill level for LN2 in the storage tank and the last three at a lower level resulting from the first expulsion (supply test). Active pressure control (APC) assessments comprise the majority of the mission events. The ordering of events had to accommodate crew availability to support orbiter operations for attitude and thruster firings for fluid positioning/settling. Two stratification tests require periods of fluid quiescence and settling using Orbiter drag to orient LN2 in the storage tank. These operations are best accomplished during crew sleep periods and do not require crew involvement. All LN2 and GN2 will be depleted and expelled to space during a nominal mission; the system will return without concern for tank residuals.

Initial On-Orbit Checkout - Prior to beginning the CONE experiment set, a checkout of the system will be accomplished. This checkout will be scheduled after the astronauts are available, usually four hours after launch. An astronaut is needed to assist in powering up the Hitchhiker and CONE payload. After that no additional support is needed until the experiment test sequence is ready to begin.

This four hour checkout will consist of cycling valves, heaters, uplinking a dummy command, downlinking data for a quicklook analysis, and the ground analyzing the downlink data. A memory readout will be included as part of the downlink. The time allotted for analysis will be determined by practice runs at the POCC well prior to launch. Two hours is an initial estimate for this function. CONE will be launched unpowered except for heater power. The crew and the ground both will be required to power up CONE, with a GO command and crew switch action in series.

Payload Control and Operation - Realtime data will be transmitted as often as available by nominal Orbiter operation which is estimated to be 90 % of the time. During times when data is not being transmitted realtime, a data record will be transferred to the Orbiter Payload Recorder. Playback of the Orbiter payload recorder to fill in the gaps from the realtime data will be required for transfer to the ground when such downlink time is available.

The on-board software will control the experiment sequences through the resident control logic in the OBC. This logic can be modified by uplinking software changes. The resident on-board sequences can also be modified by uplink commanding. Modified sequence uplinks will be based on experiment analysis at the POCC. Contingency procedures will be developed prior to the mission and tested before use.

Crew control of the operation will be from the standard switch panel at the aft flight deck. Minimal switches are available to each payload. Carrier power on/off, experiment checkout sequence start/stop, experiment test sequence start/stop, and specific valve control to safe the payload could be done from the panel (see section 5 for specific SSP function). The on-board activity includes the payload sequence and the crew operating the standard switch panel as well as reorienting the shuttle and firing thrusters and has been well documented. One prelaunch on-board activity is the setting of the standard switch panel switch to activate the TVS. The CONE experiment control functional approach is depicted in Figure 9.3-1.

Operations Priority - TVS turn on is first in order to put the experiment in its most safe configuration. After power up, active pressure control is the top priority test by technical direction from LeRC. The liquid supply test occurs before the depletion test to achieve desired fluid levels for subsequent tests. Contingency redesign is the last priority, and is used if part of the payload malfunctions or simply doesn't work as expected.

Experiment Database - The experiment and demonstration sequencing philosophy is presented in the database shown in Figure 9.3-2 and represents the logic ordering of the science to accommodate the needs of all of the required tests. The sequencing consists of experiments, demonstrations, operational holds and system operations. Test sequencing consists of several experiment groups which begin with a pressure rise experiment followed by one mixing and two pressure reduction experiments. A liquid storage demonstration follows the pressure reduction experiments to complete the group. A liquid supply and pressurant bottle recharge demonstration follows the second active pressure control group. The first liquid supply demonstration reduces tank liquid level so that the experiments and demonstrations can be repeated at the low fill level. There are several holds between groups. These holds represent logical points in the test sequence where the tests could be interrupted. Extended interruptions, however, would degrade experiment return because of the limited time to perform the required tests.

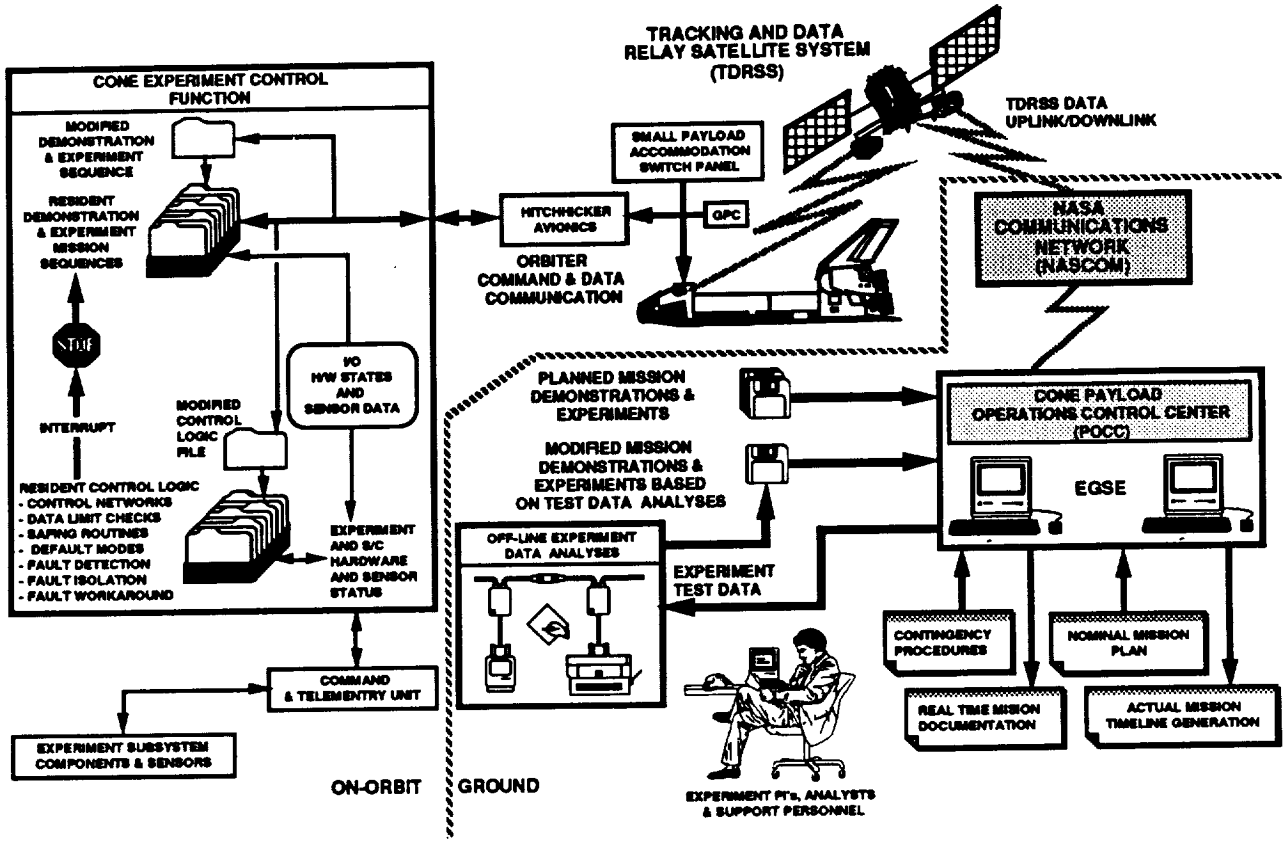


Figure 9.3-1 Experiment Control Functional Approach

The individual columns of the database are described below.

Column	Description
PRD	PRD experiment class number
Test #	The test number within the experiment class
Seq.	Test sequence index - used for database sorting
Δt	Test time in hours
Description	Brief description of the test
g's	Requested acceleration in g's
Fill %	Approximate desired fill level
Xfer Rate	LN2 supply flow rate in lb/hr
Pump #	Pump speed indicator - 0 - no flow, 1 - 110 lbm/hr, 2 - 330 lbm/hr
Heater	Heater power, including tank and vent heaters in watts
Pump	Pump power budget in watts
Thrust	PRCS thrust in lbf
D/C	Propulsion duty cycle
Prop	Consumed propellant in lbs
ΔLN2	LN2 consumed during the particular test in lbs
dM/dt	LN2 boiloff rate in lb/hr - multiplied by Δt to achieve ΔLN2 where appropriate
% Full	Calculated fill level

PRD	Test #	Seq.	Δt	Description	g's	Fill Level	Xfer Rate	Pump #	Heater	Pump	Thrust	D/C	Prop	ΔLN2	dM/dt	% Full	ΔGN2	Start t	End t
0		1	4	Orbiter Ops	BG	High	0	0	0.0	0.0	0	1	0.0	0.0	0	83.0	0	0.000	4.000
0		2	2	System Checkout	BG	High	0	0	0.0	0.0	0	1	0.0	0.2	0.114	82.9	0	4.000	6.000
5	1	3	5	APC (Stratification)	BG	High	0	0	40.0	0.0	0	1	0.0	0.0	0	82.9	0	6.000	11.000
5	5	4	0.25	APC (Mixing)	BG	High	0	1	0.0	2.5	0	1	0.0	0.0	0	82.9	0	11.000	11.250
5	9	5	1.175	APC (CHX)	BG	High	0	1	82.0	2.5	0	1	0.0	4.7	4	81.8	0	11.250	12.425
5	10	6	2.05	APC (CHX)	BG	High	0	2	122.0	5.0	0	1	0.0	8.2	4	79.7	0	12.425	14.475
1	1	7	16	LN2 Storage	BG	High	0	0	9.1	0.0	0	1	0.0	3.5	0.217	78.9	0	14.475	30.475
0		8	7	Hold	BG	High	0	0	6.1	0.0	0	1	0.0	0.8	0.114	78.7	0	30.475	37.475
5	2	9	5	APC (Stratification)	1.3E-02	High	0	0	40.0	0.0	2460	0.0011	160.0	0.0	0	78.7	0	37.475	42.475
5	6	10	0.25	APC (Mixing)	2.0E-06	High	0	2	0.0	5.0	0	1	0.0	0.0	0	78.7	0	42.475	42.725
5	11	11	0.94	APC (CHX)	BG	High	0	2	102.0	5.0	0	1	0.0	4.7	5	77.5	0	42.725	43.665
5	12	12	1.42	APC (CHX)	BG	High	0	1	142.0	2.5	0	1	0.0	7.1	5	75.7	0	43.665	45.085
1	2	13	14	LN2 Storage	BG	High	0	0	6.1	0.0	0	1	0.0	1.6	0.114	75.3	0	45.085	59.085
2	1	14	1.107	LN2 Supply	BG	High	100	0	184.0	0.0	0	1	0.0	120.7	109	45.2	7.2	59.085	60.192
0		15	2	LN2 Conditioning	BG	High	0	1	102.0	2.5	0	1	0.0	10.0	5	42.7	0	60.192	62.192
3	1	16	24	Press Recharge	BG	High	1500	0	0.0	0.0	0	1	0.0	13.0	1500	39.5	0	62.192	86.192
0	5	17	2	Hold	BG	Low	0	0	6.1	0.0	0	1	0.0	0.2	0.104	39.5	0	62.192	64.192
5	3	18	2.7	APC (Stratification)	BG	Low	0	0	40.0	0.0	0	1	0.0	0.0	0	39.5	0	64.192	66.892
5	7	19	0.25	APC (Mixing)	BG	Low	0	2	0.0	5.0	0	1	0.0	0.0	0	39.5	0	66.892	67.142
5	13	20	0.6	APC (CHX)	BG	Low	0	2	82.0	5.0	0	1	0.0	2.4	4	38.9	0	67.142	67.742
5	14	21	1.1	APC (CHX)	BG	Low	0	1	122.0	2.5	0	1	0.0	4.4	4	37.8	0	67.742	68.842
1	3	22	16	LN2 Storage	BG	Low	0	0	9.1	0.0	0	1	0.0	3.5	0.217	36.9	0	68.842	84.842
0		23	1	Hold	BG	Low	0	0	6.1	0.0	0	1	0.0	0.1	0.104	36.9	0	84.842	85.842
5	4	24	2.7	APC (Stratification)	1.3E-02	Low	0	0	40.0	0.0	2460	0.0016	120.0	0.0	0	36.9	0	85.842	88.542
5	8	25	0.25	APC (Mixing)	2.0E-06	Low	0	1	0.0	2.5	0	1	0.0	0.0	0	36.9	0	88.542	88.792
5	15	26	0.5	APC (CHX)	BG	Low	0	1	102.0	2.5	0	1	0.0	2.5	5	36.2	0	88.792	89.292
5	16	27	0.8	APC (CHX)	BG	Low	0	2	142.0	5.0	0	1	0.0	4.0	5	35.2	0	89.292	90.092
1	4	28	13.5	LN2 Storage	BG	Low	0	0	6.1	0.0	0	1	0.0	1.4	0.104	34.9	0	90.092	103.592
0		29	6	Hold	BG	Low	0	0	6.1	0.0	0	1	0.0	0.6	0.104	34.7	0	103.592	109.592
2	2	30	0.257	LN2 Supply	BG	Low	500	0	0.0	0.0	0	1	0.0	128.5	500	2.7	3.41	109.592	109.849
3	2	31	24	Press Recharge	BG	Low	500	0	0.0	0.0	0	1	0.0	6.5	500	1.1	0	109.592	133.592
6	1	32	2	LAD Depletion	1.3E-02	Low	0	0	0.0	0.0	2460	0.002	100.0	4.0	0	0.1	0	109.849	111.849
0		33	2	System Securing	BG	Low	0	0	0.0	0.0	0	0.056	0.0	0.0	0	0.1	0	133.592	135.592
	TOTALS:		161.8	Hours									380.0	332.6			10.6	Days	5.65

Figure 9.3-2 CONE Database

C-3

ΔGN2	Pressurant consumption in lbs
Start t	Starting time of the test in hrs
End t	End time of the test in hrs

The database contains information on all tests. The plots of experiment power, LN2 consumption, acceleration, pressurant mass consumption, and the timeline were produced from this database.

Orbiter Accelerations - The acceleration requirements are determined from the capability of the primary RCS thrusters and the amount of time required for settling the LN2 in the CONE storage tank. When the orbiter background or high drag acceleration modes are not used during the mission, the PRCS thrusters will be fired three short times over the mission to provide 1.3×10^{-2} g's of acceleration to the CONE experiment. The first two burns will be performed to settle the liquid in the CONE storage tank prior to conducting mass gauging and fluid thermal stratification tests. Each of these two tests will be performed for periods of 20 and 15 seconds, respectively, to settle the liquid. The final thrusting acceleration will be performed to settle the liquid in the tank prior to the last outflow which will determine the expulsion efficiency of the LAD. This thruster firing will also be for a time duration of 15 seconds, similar to the second thrusting burn.

Two different periods of high orbiter drag acceleration will be required for a series of stratification and mixing tests. The orbiter high drag acceleration is expected to be in the range of 2×10^{-6} g's. The remaining tests will be conducted at whatever background drag acceleration results, which is estimated to be about 1.5×10^{-7} g's.

LN2 Consumption Timelines - Figures 9.3-3 and 9.3-4 describe the CONE experiment LN2 that is used by each of the PRD experiments. All experiments use LN2 to varying degrees. In addition to the defined CONE experiment set, some of the orbiter functions including system checkout, and the TVS use hold periods require a small portion of experiment LN2 0.86 kg (1.9 lbm).

The largest consumption of experiment LN2, 113 kg (about 249 lbm), is by the LN2 Supply Demonstration. The LN2 supply demonstration consumes the majority of the LN2 because the tank contents have to be quickly emptied down to defined levels for testing within the mission time constraints of the Orbiter.

A relatively large quantity of LN2, 22 kg (48 lbm), is required and has been allocated for active pressure control using the compact heat exchanger (CHX). The passive TVS tests/LN2 storage tests consume 4.5 kg (10.0 lbm) and the pressurant bottle recharge demonstrations require 8.8 kg (19.5 lbm) of LN2. The LAD expulsion efficiency demonstration consumes only 1.8 kg (4.0 lbm) since its primary consumption is accounted for in the second LN2 supply demonstration.

The PRD experiment timeline database was used to extract the LN2 fluid quantity remaining in the storage tank over time. The initial tank fill level in the database is 83%, which corresponds to a starting liquid fill mass of almost 151 kg (333 lbm) of LN2 as indicated by the accompanying experiment LN2 consumption timeline chart below.

The first two sharp down ramps before outflow #1 indicate consumption of LN2 due to the first two CHX pressure reduction tests. The two gradual downslopes following them are due to the first two TVS pressure reduction tests which use substantially less LN2 than do the CHX tests. The first outflow test (outflow #1) reduces the LN2 in the tank by a major proportion until the tank contents are less than half full 80 kg (about 175 lbm). This corresponds to the lower fill level that the storage tank is depleted to for additional testing. A few more CHX and TVS pressure reduction tests require LN2 and deplete the tank to approximately 140 lbm in preparation for the second LAD outflow test (expulsion efficiency). The final expulsion test reduces the tank contents down to only 1% residual which corresponds to only a few pounds of LN2, at which point the LAD expulsion efficiency test is performed.

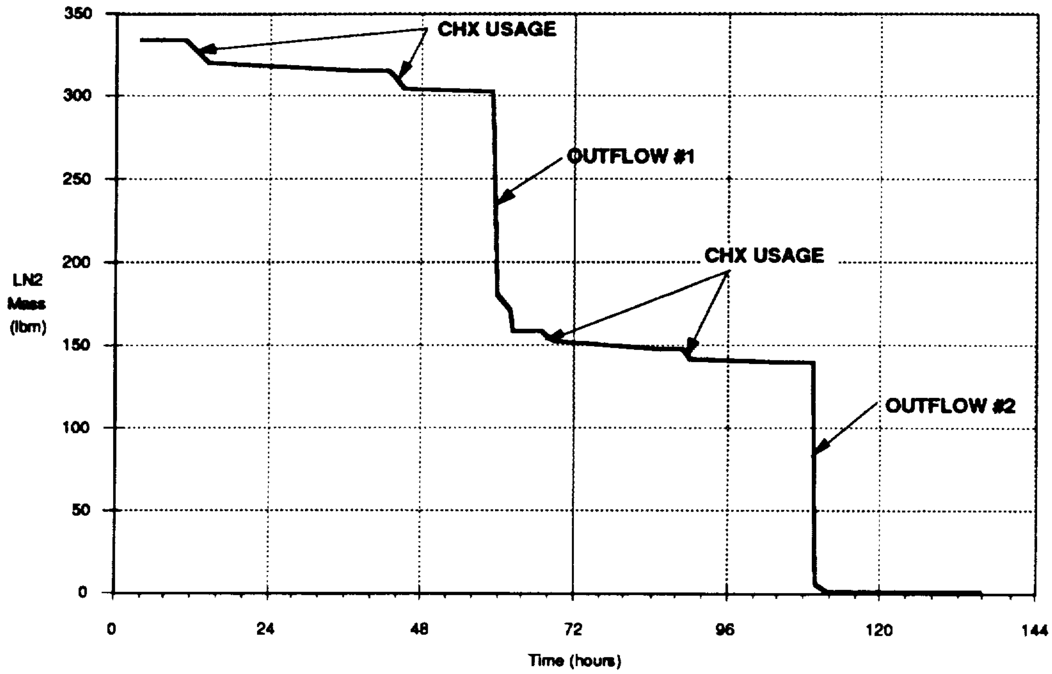


Figure 9.3-3 LN2 Consumption Timeline

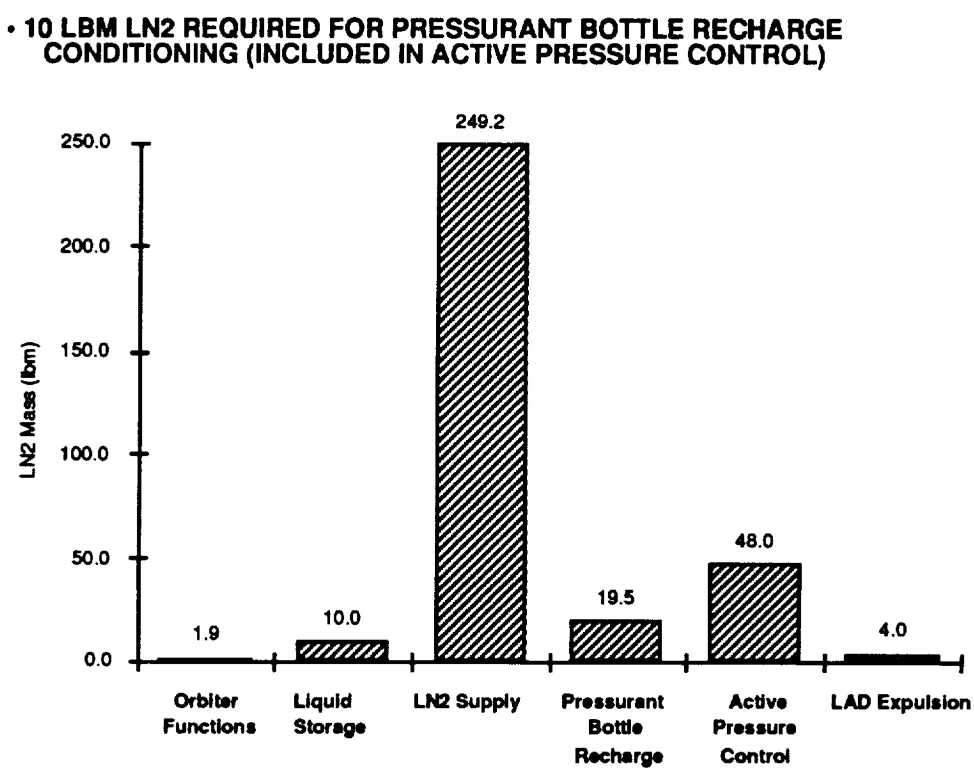


Figure 9.3-4 LN2 Consumption Timeline (by PRD)

CONE Power Consumption - The CONE payload power consumption timeline has also been produced from the PRD experiment database. The timeline is shown in Figure 9.3-5.

Excluding any of the experiment power requirements, the overall average support subsystem electronics power consumption has been conservatively estimated to be about 180 Watts (the baseline on the profile shown). The peaks shown in the curves represent experiment heater power usage rates for different phases of the CONE demonstration tests. The experiment heaters are used to heat the storage tank wall at the high heating rate 22.7 w/m^2 (7.2 $Btu/hr\text{-}ft^2$) and to condition the TVS/CHX/OHX vent flows to a warm gas condition. The CONE experiment also uses either 2.5 or 5 Watts to run the mixer pump at one of two different levels.

Power consumption on an average level is about 5.65 kWh/day. This level of power usage is well below the maximum shuttle orbiter fuel cell HH-M P/L allocation of 12.5 kWh/day.

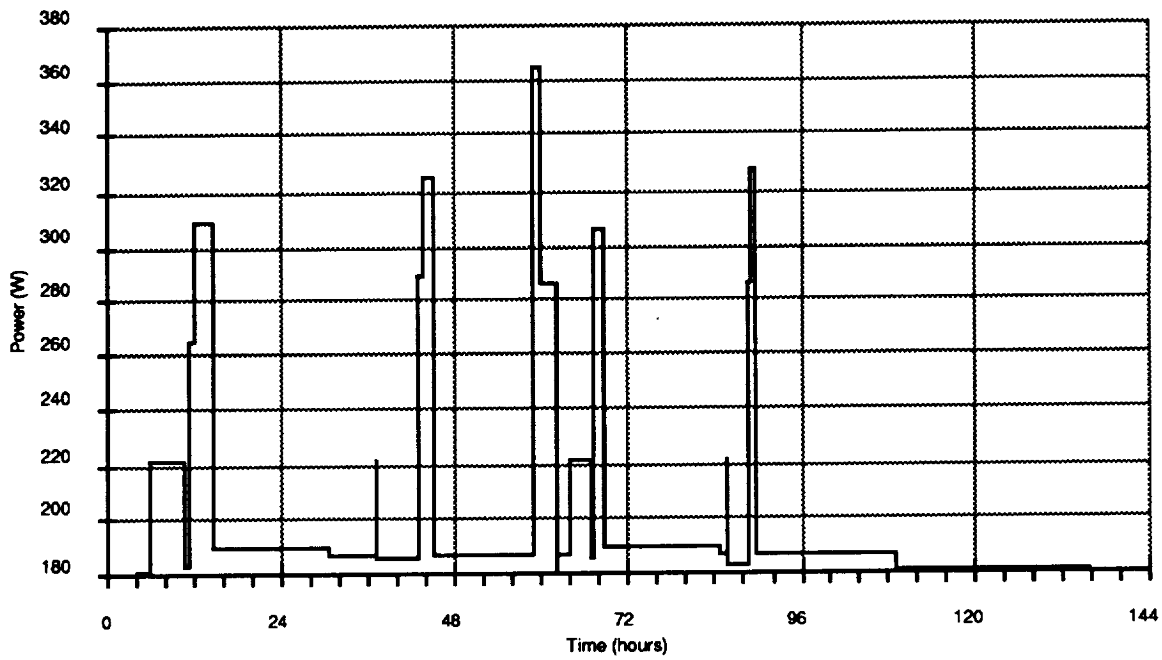


Figure 9.3-5 CONE Power Consumption

Pressurant Consumption

The pressurant mass consumption timeline is presented in Figure 9.3-6. The consumption curve illustrates that pressurant is only consumed for the two periods involving pressurant bottle chilldown and recharge, and for the liquid outflow (supply) tests. The first period of liquid outflow requires about 3.3 kg (7.2 lbm) of gaseous nitrogen and the second test requires about 1.5 kg (3.4 lbm) of autogenous pressurant.

Outflow #1 will be performed by using the pressurant available in the pressurant recharge bottle before the first time it is recharged. A substantial margin exists 2.3 kg (about 5 lbm) if required by the first outflow. However, this margin will no longer be available following the pressurant bottle recharge at which point the pressurant supply bottle (second bottle) will be available for use by the second outflow. Contingency pressurant will be available from the pressurant bottle following outflow #2 if needed. Also, additional pressurant may be available for the second outflow if the pressurant recharge bottle is warmed up adequately, but this will not be known until actual on-orbit experimentation.

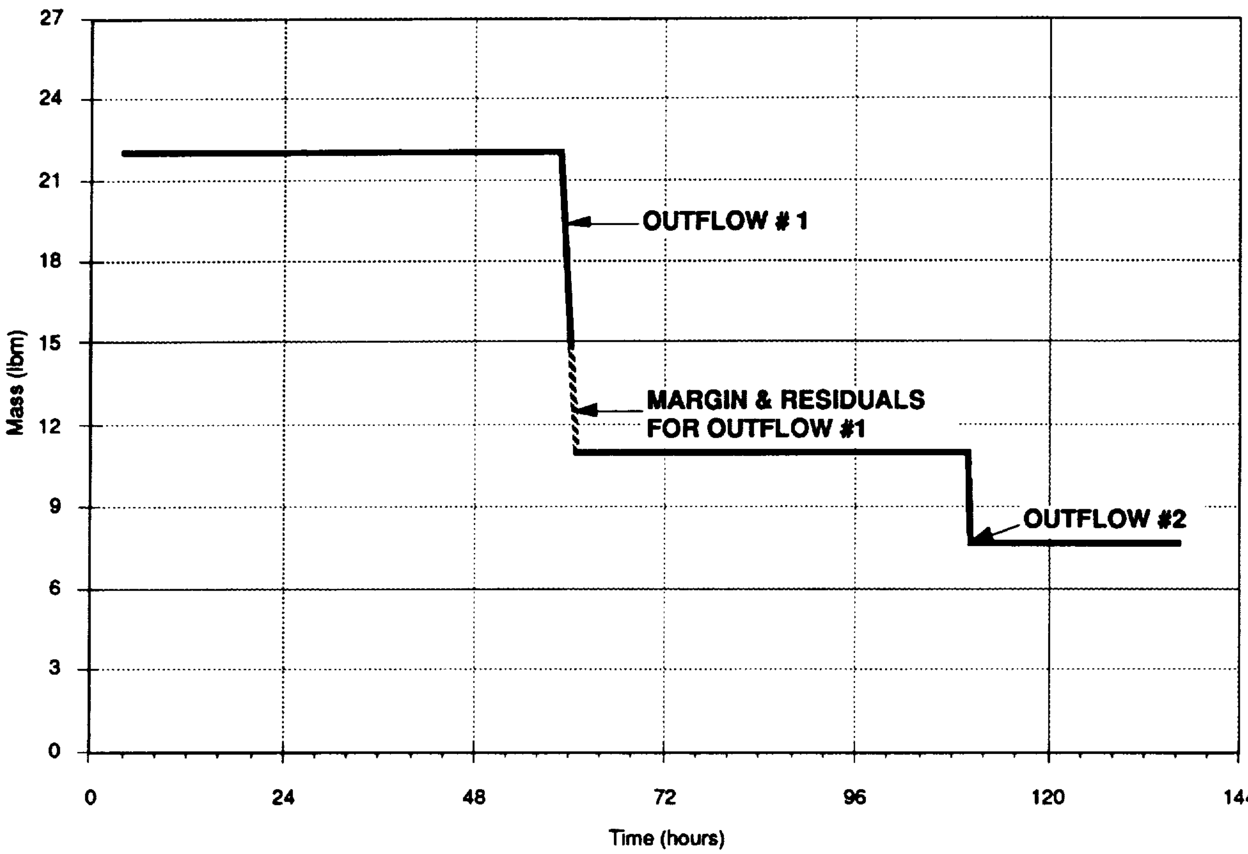


Figure 9.3-6 CONE Pressurant Consumption

9.4 Payload Operations Control Center (POCC)

The POCC provides in-flight command, control and management of flight data (both realtime and recorded) for CONE. Operations software is included in the POCC. The POCC includes a router, telemetry preprocessor, data management work stations, mission planning and scheduling work stations, personal computers for experiment monitoring and data processing and operations software.

The POCC activity for the mission starts with the training prior to the mission. This will include simulation of the mission profile and analysis activities, including contingency planning. Once on-orbit, the POCC activities will include initiating all commanding to CONE and the Hitchhiker. Payload command sequence changes will be developed and transmitted to JSC.

The CONE POCC interfaces to the flight element through the NASCOM network supplied by GSFC and coordinated with Orbiter operations through the JSC Mission Control Center in Houston (MCC-H). Data will be received on a random basis determined by Orbiter operations and TDRSS usage. Uplink commanding to modify/interrupt planned automatic events have to be coordinated with the MCC-H for transfer to the Orbiter. Orbiter attitude, position, and other ephemeris data required at the POCC can be requested. Data from the NSTS interfaces are decommutated and passed to the EGSE router system. The router selects the data and passes it to the appropriate destination--to data management for storage and to the console display system for interaction with the experiments and status of C&DH. A 9-track magnetic tape system records the low rate realtime data from the GSFC Low Rate GSE (LRGSE). Post flight analysis information will be written to the printer. An IRIG-B interface will provide timing control. The Mission Planning System (MPS) terminal is part of the GSFC POCC.

The current baseline includes five console displays: two for the experiments relating to pressure control and flow transfer, one for interaction with the C&DH health and status and command processing, one for monitor of temperature and pressure, and one for Mission Manager use of overall control and monitoring. All console displays will monitor & display safety critical parameters.

Mission Operations Team - The mission operations team shown below consists mostly of GSFC Hitchhiker personnel. CONE personnel are on the CONE Planning and Operations Team.

• CONE Payload Representatives - At MCC; speaks for CONE POCC; multishift; 24 hrs/day

• CONE Mission Manager - POCC management interface to JSC; directs CONE OD; one shift; 12 hrs/day

• CONE Operations Director (OD) - Manages generation of CONE timeline; conducts science replanning meetings; coordinates with CONE PI'S on science data acquisition and mission planning; coordinates STS and GSFC resources in support of revised science timelines; supervises operations in the ASPC and coordinates acquisition of data; multishift; 24 hrs/day

• CONE Flight Operations Controller (FOC) - Controls realtime operations of the ground system and payload; directs STS and GSFC resources in support of CONE; single point of contact with the JSC payload officer; performs command accounting; multishift; 24 hrs/day

• Data Management Coordinator (DMC) - Performs data quality checks; coordinates scheduling information transfer and distribution; coordinates data acquisition activities by the STS through JSC; maintains data switching and patch connections at the ASPC; multishift; 24 hrs/day

• Avionics Shift Manager - Manages operations of the Hitchhiker avionics and Hitchhiker ; one shift; 12 hrs/day

• Hitchhiker Operations Controller (OC) - Responsible for operation of Hitchhiker GSE within the ASPC; controls command transfer to the MCC; monitors command transmissions for HH commands received from the CONE GSE.; verifies performance of data acquisition and recording functions with the DMC; multishift; 24 hrs/day

• CONE Planning and Operations - Evaluates acquired payload data with respect to science objectives, requirements and priorities; coordinates with the CONE FOC and Hitchhiker GSE OC for command operations; multishift; 24 hrs/day; has operators to initiate commands to control the payload and to monitor payload health and operations

10.0 SAFETY

One of the most important aspects of payload use of the NSTS is to insure that the design and operation of the system meets established safety criteria, requirements and guidelines. This section presents an overview of the initiation of this safety conformance process which is an iterative and continuing activity over the duration of the payload life cycle. This activity begins early in the design process and has been completed for the efforts required for the Phase 0 safety milestone.

10.1 CONE Subsystem Hazard Group Safety Matrix

The safety matrix in Figure 10.1-1 shows the major elements of the CONE System with a lower level breakout of the flight element, as well as the major hazard groups as derived from NSTS 1700.7B. An safety hazard assessment was made of the baseline CONE experiment subsystem schematic, support subsystem approach, and operations and ground support equipment concept to identify the hazard potential for each element with respect to the listed hazard group. Both flight and ground hazards are combined on this matrix and form the total overview of hazard potential for the entire CONE System.

HAZARD GROUP / CONE ELEMENT	COLLISION	CONTAMINATION	CORROSION & MATERIALS	ELECTRIC SHOCK	EXPLOSION	FIRE	INJURY & ILLNESS	LOSS OF ENTRY	IONIZING RADIATION	NON-IONIZING RADIATION	TEMPERATURE EXTREMES
LN2 STORAGE TANK			●		●	●	●				●
GN2 PRESSURIZATION			●		●	●	●				
BOTTLE RECHARGE			●		●	●	●				●
FLUID DISTRIBUTION			●		●	●	●				●
EPS	●		●	●		●	●			●	
C&DHS	●	●	●	●	●	●	●			●	
THERMAL		●	●			●	●				
STRUCTURAL	●		●			●	●				
MGSE	●	●	●		●	●	●				
EGSE		●	●	●		●	●				

Figure 10.1-1 CONE Safety Matrix

A knowledge of what makes up the CONE System and how the system operates with a regard for hazard potential resulting form the design of operation of the system throughout ground processing, launch and on-orbit operations, as well as abort and contingency operations went into the development of this matrix. As the CONE System matures and is iterated new elements and the way they operate will be assessed for matrix update so that a current hazard potential overview of the system can be maintained at this top-most level of hazard identification. This hazard potential identification formed the first step in the CONE hazard analysis process.

10.2 CONE Identified Safety Hazards, Causes, Effects, and Suggested Controls

The top-level hazard potential matrix from Figure 10.1.1 then led to the individual identification of the specific hazard associated with each subsystem element, along with the possible effect caused by the hazard, the mission phase where the hazard potential exists, and the planned hazard control that is suggested to mitigate/control the hazard. Both ground and flight hazards are identified in this list in Table 10.2-1. Additional information on each planned hazard control is provided below and corresponds to the item listed in the table:

1. Existing pressurant bottles delivered under the CFME contract have a minimum burst pressure rating of 6400 psi. CONE pressurization needs can be adequately met with 3000 psi GN2 pressure. This operational constraint provides a safety factor greater than 2 to 1 and provides adequate flexibility in where and when the bottles can be serviced. Constraints for working around the bottles when pressurized will be imposed.

2. Standard circuit and wiring design supported by analysis and test along with adequate circuit protection will be implemented to insure that bus overloading and/or burning of wire insulation does not occur.

3. The storage tank design concept provides for manual LN2 servicing/deservicing. Power is not required for launch, ascent or landing.

4. All materials used on CONE will have known flammability characteristics (Ref JSC-09604 & JSC-02681). A detailed parts and material list will be provided and submitted to the JSC Materials Technology Branch for review and concurrence as part of the P/L integration and safety review process.

5. Electronic circuits will be designed to limit susceptibility to conduct and radiate electromagnetic interference per MSFC-SPEC-521. Electrical shielding, grounding and bonding will limit similar problems per MSFC-SPEC-521 and MIL-STD-5087B.

6. An analysis will be performed on each vented electronic/electrical box to insure structural integrity of the container during ascent/descent with pressure relief devices as appropriate. Sealed containers will be designed to withstand internal or external vacuum.

7. Ultimate factor of safety is at least 1.5 for tested structural members. Ultimate factor of safety is at least 2.25 for untested structural members that are fail safe. Both will use worst case loads imposed by any mission phase. A fracture control plan will be implemented to minimize the chance of failure from detected and undetected flaws.

8. All flight and GSE lines that are exposed to LN2 flow during fill/drain operations or are exposed to LN2 in a venting or static condition will be insulated with 0.5 inches of polyurethane (or other) foam. Certain exposed GSE lines will be controlled procedurally.

9. CONE EGSE will be designed in accordance with NEC and JSC-SE-E-0002 for grounding and over current protection. No access will be allowed to powered equipment internals. Cable connections will be controlled by design and procedure to preclude improper installation and will only be mated/demated with power removed.

10. All materials used on CONE will have known flammability, outgassing and toxic characteristics (Ref JSC-09604 & JSC-02681). A detailed parts and material list will be provided and submitted to the JSC Materials Technology Branch for review and concurrence as part of the P/L integration and safety review process.

Table 10.2-1 Identified Safety Hazard List

Subsystem	Hazard Description	Possible Hazard Effect	Mission Phase Affected	Hazard Control
1 Experiment and GSE	High pressure gas pressurization ruptures/leaks GN2.	Explosion or Impingement	Manuf/Test Ground Ascent On-Orbit Abort Landing	Adequate margins and safety factors complemented with extensive ground testing.
2 EPS/C&DH	Electrical system becomes overloaded.	Fire, Orbiter Damage	Manuf/Test Ground Ascent Landing	Adequate margin and fuses.
3 EPS/C&DH, Experiment Subsystem	Electrical/electronic parts which can arc/spark could provide an ignition source in a flammable/explosive atmosphere within the Orbiter Payload Bay compartment or test facility area.	Fire and/or Explosion	Manuf/Test Ground Ascent Landing	Explosion proof electrical design. Power down of equipment when not needed.
4 All	Use of combustible materials in combination with an ignition source presents a fire hazard.	Fire, Orbiter Damage	Manuf/Test Ground Ascent Landing	Material controls and review to preclude/ minimize combustible material use.
5 C&DH/EPS	EMI/ESD generated by the CONE interferes with the STS during flight.	Orbiter Damage, Electrical Equipment Damage	Ground Ascent On-Orbit Landing	EMI design margin. Adequate shielding, bonding and grounding.
6 EPS/C&DH	Rupture or implosion of sealed/vented containers could cause collision damage with the Orbiter.	Orbiter Damage, Injury	Ascent On-orbit Descent	Adequate design margin, safety factors and relief protection.
7 Structural and GSE	Structural failure of primary structures, handling equipment and/or lifting equipment could cause collision damage.	Collision Injury, Orbiter Damage	All	Adequate margins and safety factors with extensive ground testing & procedural control.
8 Experiment and GSE	Personnel/EVA astonaut contact with cold surfaces could result in freeze burns to the skin.	Personnel Injury	Manuf/Test Ground	Adequate insulation to minimize cold surfaces. Personnel protective equipment.
9 EPS/C&DH GSE	Accidental contact by personnel with AC or DC voltage could result in personnel shock or electrocution.	Electrical Shock	Manuf/Test Ground	Adequate guards will be provided. Sealed equipment.
10 All and GSE	Use of hazardous, combustible or outgassing materials could result in equipment damage or injury to personnel.	Fire and/or Explosion, Injury, Orbiter Damage	All	Use and control of using such materials only when necessary.
11 EPS	Battery failure causes leakage of caustic contents	Orbiter & Equip Damage, Personnel Injury	All	Flight qualified batteries, material margin and testing.
12 EPS	Battery rupture/explosion.	Orbiter & Equip Damage, Personnel Injury	All	Flight qualified batteries, material margin and testing.

Table 10.2-1 Identified Safety Hazard List Continued

Subsystem	Hazard Description	Possible Hazard Effect	Mission Phase Affected	Hazard Control
13 Experiment and GSE	LN2 trapped in lines between positive shutoff devices could expand and create overpressure conditions or line ruptures.	Orbiter Damage, and/or Explosion, Injury, Impingement	All	Provide appropriate relief protection or procedural control to preclude trapping LN2.
14 Experiment, Thermal and GSE	Improper material (both metal and soft-good) when exposed to LN2 and/or cryogenic temperature result in damage.	Orbiter Damage	All	Compatibility of materials with LN2 and cryogen temperatures, redundant shutoff/sealing devices, component qualification and control of vent effluents in the P/L bay.
15 Experiment, Thermal and GSE	During venting LN2 can freeze resulting in restricted flow or blocked lines. Contents of storage tank may not be completely expelled.	Orbiter Damage	Manuf/Test Orbit	Preclude freezing by maintaining pressures above 2 psia. Use heater protection where required. Control venting rates.
16 Experiment and GSE	Moisture or other contaminants intrude into the system which may clog or prevent component operation. Ruptures could occur.	Orbiter Damage, and/or Explosion, Injury	Manuf/Test Ground	Proper procedure, purging and system protection to prevent intrusion.
17 Experiment	Supply tank vacuum jacket fails resulting in uncontrolled venting which dump tank contents.	Orbiter Damage, Injury	Manuf/Test Ground Ascent Landing	Adequate VJ margins and test approach. Limiting venting rates with foam protection. Proper routing of vent effluents in the P/L bay.
18. Experiment GSE	Use of LN2/GN2 results in loss of habitable/breathable atmosphere during ground operations.	Injury/Illness	Manuf/Test Ground	Adequate design margins, safety factors and test controls.
19. Experiment Support Subsystems	Exposure of the crew to sharp edges, corners or protrusions.	Injury	On-Orbit	Adequate design for rounding/chamfering & protrusion minimization.
20. GSE	Contamination of the Orbiter/ Payloads by materials, debris and tools.	Orbiter Damage, Injury	Ground	Limit and control such operations in the bay.
21. Experiment	Uncontrolled venting of LN2 and improper vent discharge on Orbiter surfaces.	Orbiter Damage	Ground Ascent On-Orbit Landing	Limit venting potential with adequate thermal protection. Provide optimal vent line routing.
22. C&DH	Inadvertant commanding can create a hazardous CONE configuration.	Orbiter Damage	Ground Ascent On-Orbit	Appropriate ground and flight S/W protection and equipment powerdown when not needed.

11. Battery requirement is for computer memory keep alive which uses TBD size cells that are flight qualified, shelf life controlled and are confined in a suitable container.

12. Battery type and loading use limit the potential for this failure. Packaging in a suitable container will contain all debris and contents should the failure occur.

13. All volumes having a potential for trapping LN2 will first be procedurally controlled to vent the volume before lock-up can occur. Secondly they will be provided with control network automatic protection to open valves and relieve pressure and finally a manual over pressure device will be provided.

14. All materials used on CONE coming in contact with LN2 will have known compatibility characteristics (Ref JSC-09604 & JSC-02681). A detailed parts and material list will be provided and submitted to the JSC Materials Technology Branch for review and concurrence as part of the P/L integration and safety review process.

15. Tank outflow to space will be controlled with back pressure and heater protection for low flow applications. High flow situations will have high enough flow rates and large line size to limit the potential for freezing.

16. Prior to the introduction of LN2 or cold GN2 the affected system element will be purged with ambient GN2. Purity levels of all commodities introduced into the system will be controlled. Payload bay purge air and GN2 contain low levels or moisture.

17. The storage tank thermal control approach includes 0.75 in of foam insulation that will limit worst case ground emergency venting to an average of 30 lb/hr. The vacuum jacket and the pressure vessel will have high design margins and will be thoroughly tested. In bay vent routing will be optimized to heat sink the line to suitable CONE & carrier structure and will be equipped with line heaters to insure gas at the exit.

18. All external leakage potential of GN2 from GSE and flight equipment will be controlled by adequate design margins, safety factors and test controls that will limit the flow rate of gases and liquids to acceptable flow rates and pressure levels.

19. All equipment will be designed for mitigating sharp edges.

20. Operational procedures will limit materials, tools and equipment that enter the Orbiter for testing and servicing operations . Tethers and restraints will be used where required. Logging of items into and out of the test area will be used.

21. The exit and routing of the in-bay vent will be optimized to maximize intercepted structural heat and discharge effluents at a proper and approved location and at a controlled vent rate (30 lb/hr maximum). Nominal rates will insure that only cold gas and no liquid exits the vent. On-orbit a dedicated high flow vent to space will be used.

22. S/W will be designed to limit this potential, as well as processor control. The CONE will not be powered up during ascent. Power will not be applied until after the P/L bay doors are opened. Certain valves may be commanded only from the SSP.

10.3 CONE Concept Experiment Subsystem Safety Features

As the CONE experiment subsystem design approach evolves, safety features will be incorporated that provide for the following:

1. Adequate structural safety factors.
2. Adequate pressure vessel safety factors.
3. Dual pressure relief for the storage tank and vacuum jacket.
4. Proof pressure testing for all pressurized systems.
5. Sizing of wires, circuit breakers and fuses will be of adequate safety factors.
6. Analysis will be performed to determine the possibility of arcing and sparking.

7. Electronic/electrical components will be selected to preclude arcing and sparking.
8. All materials will be submitted to JSC for review and concurrence.
9. Adequate bonding and grounding to preclude the buildup of static charge.
10. Analysis/testing to verify generated EMI is within tolerable levels.
11. CONE will be safe without the need for ground or flight services.
12. Three inhibits will preclude dumping LN2 into the bay before the P/L bay doors are open.
13. Both active processing and manual relief protection will be used for over pressure protection.
14. Optimize vent line placement and exit discharge.
15. Provide ullage venting of storage tank in vertical and horizontal positions.
16. Foam insulation controls storage tank boiloff to an acceptable level.
17. System is safe if returned from orbit with LN2 and GN2.
18. System is safe with a loaded tank in the abort landing horizontal attitude.
19. No power is required for LN2/GN2 fill/drain.

Figure 10.3-1 Depicts the CONE Experiment Subsystem Safety Features.

10.4 Abort Landing Safety Approach

The CONE LN2 storage tank has to be capable of an Orbiter abort landing in the horizontal attitude and be safe during long periods of time when it may be unattended and cannot be monitored. This requirement led to the configuration with the CONE landing with LN2 in the storage tank with a liquid level below the pressurant diffuser. The tank vent was configured so that it would be positioned in the ullage space for both the normal vertical and contingency horizontal attitude. Dual burst disks and relief valves provide over pressure protection at 345 kN/m^2 (50 psia) for a worst case locked-up tank. If the tank was locked up at launch, tank pressure will increase until pressure relieves 345 kN/m^2 (50 psia). If the TVS was on at launch, gas would be vented to maintain the tank at ambient pressure since the TVS inlet is at the top of the tank in the ullage space. Leaving the TVS on at launch is the current planned configuration of the LN2 storage tank. In an abort landing situation the TVS would vent and control the tank pressure since the TVS inlet is at the top of the tank in this attitude. The tank would slowly boiloff in this mode and would vent approximately 0.5 lb/hr.

The storage tank would be completely safe with the tank locked up or with the TVS on. The slow TVS controlled vent results in the maintenance of a lower tank pressure with reduced but continuous venting into the cargo bay is the recommended approach. Periodic relief valve cycling between 310-345 kN/m^2 (45-50 psia) would vent colder gas into the bay at higher rates and could would present more of a thermal concern than the TVS approach.

10.5 NSTS P/L Safety Requirements Applicability Matrix

Certain system program requirements have to addressed as part of the STS safety review and certification process. This process consists of performing safety analyses, identifying hazards, reducing hazards potential, supporting safety reviews, providing safety certification of the P/L, and providing other safety compliance data. This process has been initiated for CONE on an informal bases and has taken the form of a preliminary safety assessment of the CONE Conceptual Design and the generation of hazard reports which would be required for a Phase 0 safety review. The Phase 0 safety review package has also been prepared.

The matrix shown in Table 10-2 provides a cross reference of NSTS safety requirements and identified hazard reports generated with respect to CONE P/L element involvement. Where possible the 22 individual hazards identified have been grouped where appropriate into combined hazard reports for both flight and ground categories.

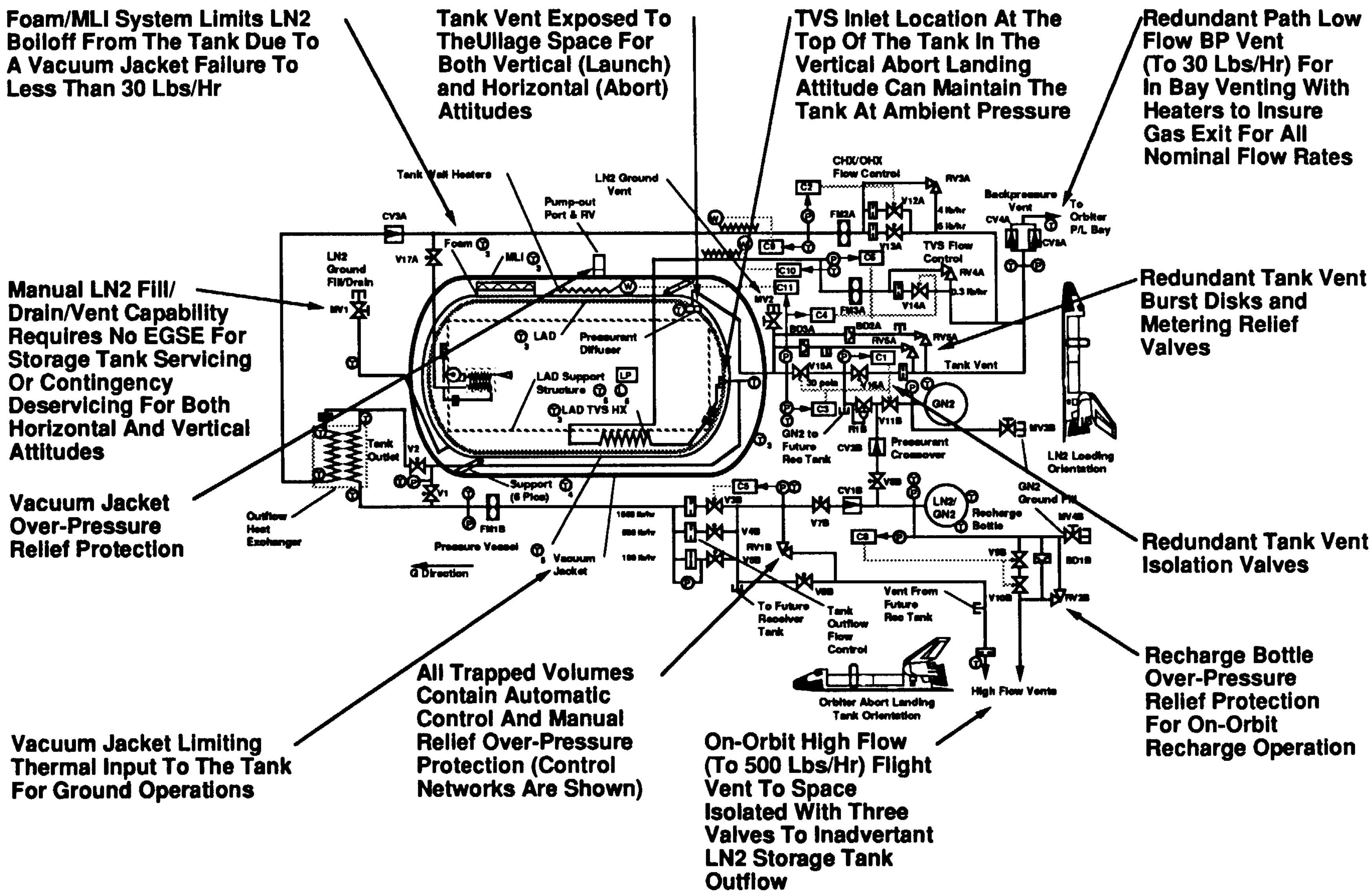


Figure 10.3-1 CONE Concept Experiment Subsystem Safety Features

Based upon the CONE Hazard Analysis, eight (8) individual Payload Hazard Reports (PHR) for payload design and flight operations, and six (6) for ground have been prepared and are organized as follows:

Hazard Group (Flight)	Hazard Report No.
Collision (Structural - Support)	CONE - 01
Collision (Structural - Experimental)	CONE - 02
Contamination, Corrosion & Materials, Temperature Extremes, Injury/Illness (Structure, Experiment, Thermal Control)	CONE - 03
Electrical Shock/Injury (EPS, C&DHS, Mass Gaging)	CONE - 04
Fire/Injury (All)	CONE - 05
Injury/Illness (Experimental, Support)	CONE - 06
Non-Ionizing Radiation/Injury	CONE - 07
Non-Ionizing Radiation	CONE - 08

Hazard Group (Ground)	Hazard Report No.
Collision/Injury (Structures, Lifting & Handling)	CONE G 01
Collision/Injury (Pressure)	CONE G 02
Contamination, Corrosion & Materials, Temperature Extremes, Injury/Illness	CONE G 03
Fire/Injury Flammable Materials and ignition source	CONE G 04
Injury/Illness (System	CONE G 05
Electrical Shock/Injury (EGSE-MGSE)	CONE G 06

JSC Form 1090, STS Payload Safety Requirements Applicability Matrix is shown in Table 10.5-1 for these eight hazard report categories. See DRD 16 Phase 0 Safety Compliance Data Package for Payload Design and Flight and Ground Operations for a complete definition of the CONE Hazard Analysis for both flight and ground hazards.

PAYLOAD: CRYOGENIC ON-ORBIT NITROGEN EXPERIMENT	DATE: APRIL 3, 1991	PHASE 0	PAGE 1 OF 1

GENERAL REQUIREMENTS

NSTS 1700.7B REQUIREMENTS	200 GENERAL	201 HAZARDOUS FUNCTIONS	203 RETRIEVAL OF PAYLOAD	204 HAZARD DETECTION/SAFING	205 CONT. RETURN/ RAPID SAFING	206 FAILURE PROPAGATION	207 REDUNDANCY SEPARATION	211 DESTRUCT SYSTEMS	213.3 LIGHTNING	214 VERIFICATION	215 HAZARDOUS OPERATIONS	216 SERIES PAYLOAD	216 REFLOWN HARDWARE	217 PLANNED EVA	218 PAYLOAD COMMANDING	220 MAN-TENDED PAYLOAD
PAYLOAD APPLICABILITY	X	X				X				X						

SPECIFIC PAYLOAD HAZARDS

PAYLOAD ELEMENT OR SYSTEM	202.1 SOLID PROPELLANT	202.2 LIQUID PROPELLANT	202.3 DEPLOYMENT/ JETTISON	202.4PLANNED EXTENSION	202.5 RF RADIATION	208.1 , 2 & 3 STRUCTURES	208.4 PRESSURE SYSTEMS	208.5 SEALED COMPARTMENTS	209.1 HAZARDOUS M ATERIALS	209.2 FLAMMABLE MATERIALS	209.3 OFFGASSING MATERIALS	210 PYROTECHNICS	212.1 IONIZING RADIATIONS	212.2 NONIONIZING RADIATION	212.3 LASERS	213 ELECTRICAL SYSTEMS	213.2 BATTERIES	219 FLAMMABLE ATMOSPHERES
						1,2, 3,6	2,3, 6,7	2,6, 7	3,5, 6	3,5, 6	3,5, 6			5,7, 8		4,5, 6,7, 8		
SUPPORT SUBSYSTEMS																		
STRUCTURES SUBSYSTEM						X			X	X	X							
ELECTRICAL POWER SUBSYSTEM								X	X	X	X			X		X		
C&DHS SUBSYSTEM							X	X	X	X	X			X		X		
THERMAL CONTROL SUBSYSTEM							X		X	X	X			X		X		
EXPERIMENT SUBSYSTEM																		
LN2 STORAGE TANK SUBSYSTEM						X	X		X	X	X					X		
GN2 PRESSURIZATION SUBSYSTEM							X		X	X	X					X		
FLUID DISTRIBUTION SUBSYSTEM							X		X	X	X					X		
BOTTLE RECHARGE SUBSYSTEM							X		X	X	X							
MGSE																		
EGSE																		

	IMPLEMENTATION PERSONNEL	DATE	PAYLOAD ORGANIZATION PERSONNEL	DATE
PREPARED BY				
REVIEWED BY				
APPROVED BY				

Table 10.5-1 NSTS Safety Matrix

11.0 RELIABILITY

The reliability analysis performed on the CONE experiment assumes a single string configuration with the appropriate duty cycle applied to each component. The non-operational failure rate used is 10% of the operational failure rate. A mission duration of six days is used in the calculations. The failure rate for all passive structures is assumed to be zero and the Hitchhiker Avionics Unit was not included in the analysis. Where complete component information was unavailable, a generic item was used in the calculations.

The results of the analysis show a CONE probability of success of .99322 for the six day mission. This value may increase as more detailed subcontractor data becomes available.

• SYSTEM CONFIGURATION

• SYSTEM RESULTS
- PROBABILITY OF SUCCESS = .99322

*** INCLUDES THE EVE**
***** SCI MIT CONFIGURATION**

Figure 11.0-1 CONE Reliability

The preliminary high reliability result indicates that no added redundancy is necessary for reliability purposes. Additional redundancy may be required to satisfy safety requirements.

<u>Redundancy</u>

The concept selected for CONE uses the Hitchhiker Avionics which are single string. In keeping with this single string philosophy, the CONE design is shown without redundancy because the reliability of the system is so high for a very short mission. Certain safety-related items will be redundant, but the majority will not be.

If the desire to include more redundancy mandates additions, the items listed will be necessary.

*EXTRA PRESSURANT BOTTLE AND PRESSURANT
*REDUNDANT C&DH CARDS
*REDUNDANT HITCHHIKER PORTS
*REDUNDANT VALVING (6)
*REDUNDANT SENSORS
*ADDITIONAL PLUMBING LINES
*ADDITIONAL SOFTWARE

12.0 PROJECT IMPLEMENTATION AND DEVELOPMENT PLANNING

The project planning activity prepared for the CONE development addresses our approach to the detailed design, development, fabrication, test, ground processing and mission support for the CONE system which includes related GSE. The Phase C/D program that is outlined runs through post-mission analysis and is almost 5 years in length ending in 1998.

12.1 Technology Risk Categories - Assessment

To perform a preliminary assessment of the state of the technology required to successfully execute the mission, we have assigned to each subsystem the risk rank as specified in the SOW .

In our judgement, category (a) risk range specifies that the hardware is used with no modifications to the existing qualified design and includes no changes in the interfaces. The mechanical interfaces and the environments provided by the STS on the carrier must meet the specifications to which the hardware was qualified. A rating of "0" would only be assigned to hardware that is "on-the-shelf", built and tested. From this existing hardware category, the next class category (b) is hardware with new designs that use existing and proven designs and have heritage to designs that that have been used before. A good number of experiment subsystem components/elements fall into this category. Category (c) hardware introduces technology risk that requires new designs that are at or near the state-of-the-art of technology and do not have proven flight heritage or similarity to other flight proven systems/components. Only the mixer pump and the continuous liquid level probe have been identified that fall into this category. The last category (d) defines technology risk required to meet experiment objectives that is beyond the current state-of-the-art. No CONE needs have been identified that fall into this highest risk category.

Table 12.1-1 defines the risk factor ranking ranges. A risk factor by subsystem element has been assigned in Table 12.1-2 and is a summary of the subelement risk detailed in Table 12.1-3 and -4 for both the support and experiment subsystems, respectively.

Table 12.1-1 Risk Ranking

STATE OF TECHNOLOGY CATEGORY	RISK RANGE ASSIGNED
a. USING EXISTING HARDWARE OR QUALIFIED DESIGNS	0 TO 1
b. REQUIRE NEW DESIGNS- EXISTING PROVEN TECHNIQUES ARE AVAILABLE	2 TO 4
c. REQUIRE NEW DESIGNS- AT OR NEAR THE STATE-OF-THE ART OF TECHNOLOGY	5 TO 7
d. REQUIRE NEW DESIGNS- BEYOND THE CURRENT STATE-OF-THE-ART	8 TO 10

Where : a risk factor of 10 indicates the highest degree of risk;

a risk factor of 0 indicates essentially risk free.

Table 12.1-2 Risk Factors by Subsystem

SUBSYSTEM	RISK FACTOR (category)		HERITAGE
Carrier HH-M	0	(a)	See Support Subsystem Risk Charts
C&DH	1-2	(a-b)	See Support Subsystem Risk Charts
Electrical Power	1-2	(a-b)	See Support Subsystem Risk Charts
Thermal	1	(a)	See Support Subsystem Risk Charts
Structure	1	(a)	See Support Subsystem Risk Charts
Experiment	1-5	(a-c)	See Experiment Risk Charts
Ground Element	1-2	(a-b)	See Support Subsystem Risk Charts
Software	2	(b)	See Support Subsystem Risk Charts

Table 12.1-3 Support Subsystem Risk Factors

SUBSYSTEM	RISK FACTOR/ CATEGORY	HERITAGE
ELECTRICAL POWER		
PDU	1-2/a-b	SCI UDACS - IECM (INDUCED ENVIRONMENTAL MONITOR)
CABLING	1/a	MAGELLAN/VIKING
COMMAND & DATA HANDLING		
C&DH UNIT	1-2/a-b	SCI MICRODACS
HITCHHIKER AVIONICS UNIT	0/a	HITCHHIKER
ON BOARD COMPUTER	1/a	80C86
EXPERIMENT VALVE ELECTRONICS	2/b	MMS PROPULSION MODULE ELECTRONICS
STRUCTURES		
MPESS CARRIER	0/a	HITCHHIKER
TOP AND SIDE INTERFACE PLATES	1/a	HITCHHIKER
STORAGE TANK SUPPORTS	2/b	TITAN/MAGELLAN/VIKING
PRESSURANT BOTTLES SUPPORTS	2/b	TITAN/MAGELLAN/VIKING
HH-M BRIDGE TRUNNION ATTACHMENT	0/a	HITCHHIKER
THERMAL		
MLI	1/a	TITAN/MAGELLAN/VIKING
HEATERS	1/a	TITAN/MAGELLAN/VIKING
THERMOSTATS	1/a	TITAN/MAGELLAN/VIKING
SOFTWARE	2/b	MIT PAYLOAD-SPACE BASED VISABLE (SSTS MSX SPACECRAFT) EXPERIMENT
GROUND SYSTEM		
MGSE	1-2/a-b	TITAN/MAGELLAN/VIKING
EGSE	1-2/a-b	SCI MICRODACS STE

Table 12.1-4 Experiment Subsystem Risk Factors

SUBSYSTEM	RISK FACTOR/ CATEGORY	HERITAGE/VENDOR
LN2 STORAGE TANK		
• LAD	2-3/b	PM/L-SAT/IRAD/RCS - MMAG
• Mixer Pump	5/c*	IRAD D-72D - BARBER NICHOLS
• Mixer Pump Screen Trap	2/b	PM/L-SAT/IRAD/RCS - MMAG
• CHX	2-3/b	IRAD - MMAG
• TVS	2-3/b	IRAD - MMAG
• JT Expander	4/b	IRAD - LEE CO
• Check Valves	2/b	CIRCLE SEAL
• Axial Jet	2/b	MMAG/SPRAYING SYS INC
• Temp & Level Sensors	2/b	ROSEMOUNT/OMEGA/LAKESHORE
• Liqiud Level Probe	5/c	PSI/PSM/SPINCRAFT
• Pressure Vessel (PV)	2/b	LAKESHORE/ILLINOIS SUPERCOND
• PV Wall Heaters	2-3/b	TAYCO
• PV/VJ Supports	3-4/b	MMAG/SCI
• Penetrations	2/b	MMAG/BI-BRAZE
• Foam/MLI	2-3/b	ET/IRAD/STS - MMAG & VARIOUS
• Vacuum Jacket (VJ)	2/b	PSI/PSM/SPINCRAFT
• Pump-out Port/RV	1/a	CVI

*** Based on successful prototype LN2 mixer pump development and testing being conducted in-house by MMAG**

SUBSYSTEM	RISK FACTOR/ CATEGORY	HERITAGE/VENDOR
GN2 PRESSURIZATION		
• 3000 Psi GN2 Storage Tank	1/a	CFMF - PSM
• 3000 Psi GN2 Electric Valve	1-2/a-b	COBE - EATON
• Fixed GN2 Regulator	3/b	MMU - STERER
• 3000 Psi GN2 Manual Service Valve	1-2/a-b	MMU - PYRONETICS
• 4000 Psi Pressure Transducer	1-2/a-b	TAVIS
• Temp Sensor	1-2/a-b	ROSEMOUNT
LN2 RECHARGE BOTTLE		
• 3000 Psi LN2 Recharge Bottle	3/b	CFMF - PSM
• 3000 Psi LN2 Electric Valve	4/b	KETEMA
• LN2 Check Valve	2/b	CIRCLE SEAL
• 3300 Psi Burst Disk	2/b	KETEMA - VIKING
• 3300 Psi Relief Valve	2/b	KETEMA
• 4000 Psi Pressure Transducer	1-2/a-b	TAVIS
• Temp Sensor	1-2/a-b	ROSEMOUNT
• Flow Control Orifice	1-2/a-b	MMAG/LEE CO

Table 12.1-4 Experiment Subsystem Risk Factors (Continued)

SUBSYSTEM	RISK FACTOR/ CATEGORY	HERITAGE/VENDOR
FLUID DISTRIBUTION		
• TVS Flowmeter	4/b	FLOW TECHNOLOGY INC
• CHX Flowmeter	4/b	FLOW TECHNOLOGY INC
• OHX Flowmeter	4/b	FLOW TECHNOLOGY INC
• Flowmeter Heaters	2/b	TAYCO
• 50 Psi Pressure Transducer	1-2/a-b	TAVIS
• Temp Sensors	1-2/a-b	ROSEMOUNT
• Flow Control Orifices	1-2/a-b	MMAG/LEE CO
• LN2 Electric Isolation Valve	4/b	FLODYNE
• LN2 Manual Service Valve	1-2/a-b	MMU - PYRONETICS
• Outflow Line Flowmeter	3-4/b	FLOW TECHNOLOGY INC
• OHX	3/b	IRAD/MMAG
• OHX JT Expander	3/b	IRAD/LEE CO
• Relief Valves	2-3/b	KETEMA
• Check Valves	2-3/b	CIRCLE SEAL
• Vent Diffuser	2/b	MMAG

A risk factor by support subsystem element has been assigned in Table 12.1-3 and and is based on knowledge of the component complexity and judgement as to the state of component development required to meet CONE needs and is also somewhat influenced by the heritage listed in the last column. All parts of the CONE support subsystem use existing technology for components that already exist or that are in advanced stages of development and certification for Orbiter in-space use.

A risk factor by each experiment subsystem element has been assigned in Table 12.1-4 and is based on knowledge of the component complexity and judgement as to the state of component development required to meet CONE needs. It is also somewhat influenced by the heritage, vendor state of qualification for use and amount of modification that will have to be made to the component. This heritage and vendor information is listed in the last column.

12.2 CONE Phase C/D Work Breakdown Structure

Figure 12.2-1 shows our recommended Work Breakdown Structure (WBS) for the CONE Phase C/D program. Eight second-level tasks have been defined along with appropriate third-level task breakouts. Each third-level task is further subdivided into subtasks at the cost account level where all work will be performed and costs will be tracked. This WBS was then used to produce a program schedule that is included in this section and a detailed logic network that has been delivered to NASA-LeRC. A detailed WBS Dictionary for the Phase C/D CONE program has been prepared to explicitly define the work contents for each level entry.

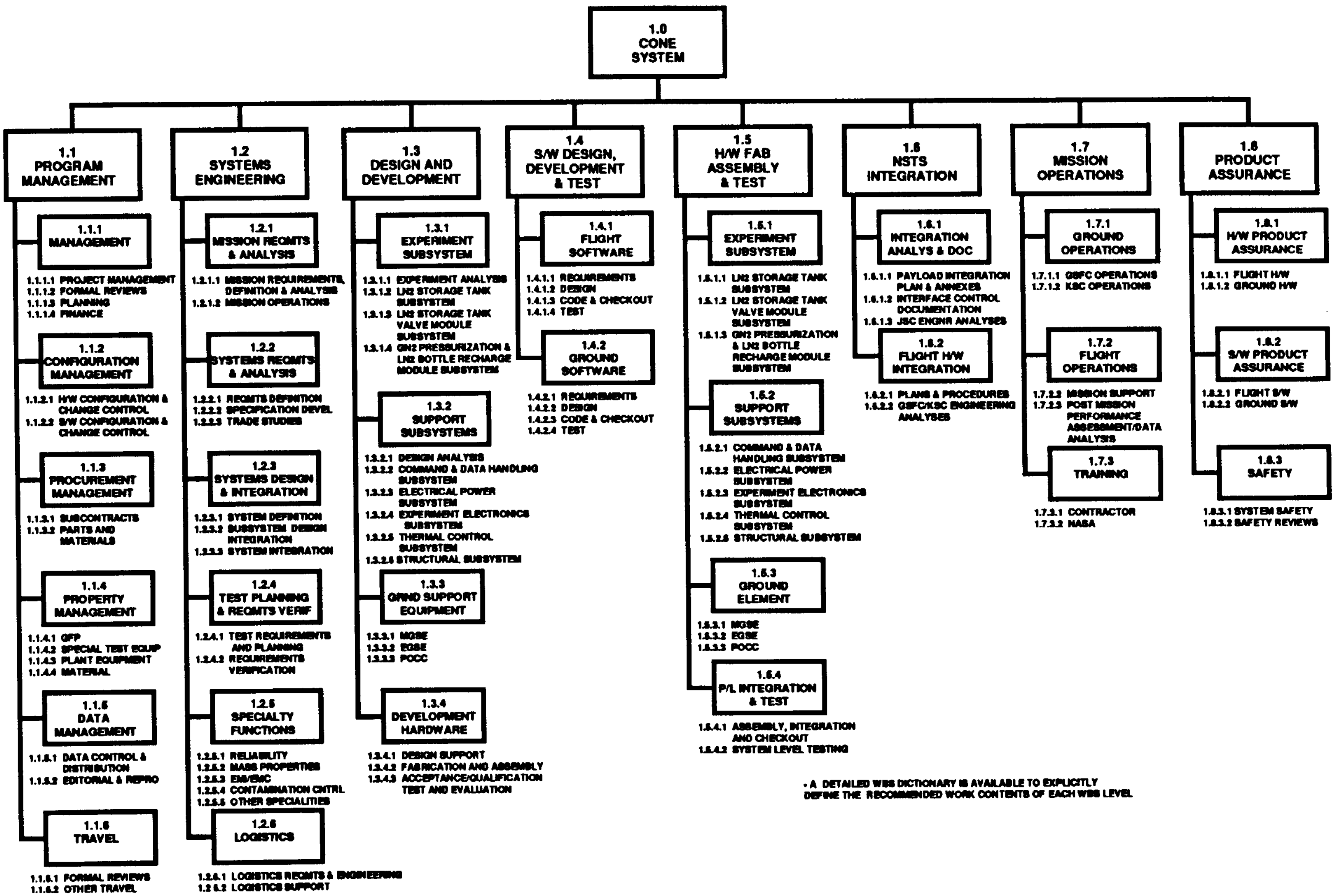


Figure 12.2-1 Work Breakdown Structure (WBS)

12.3 CONE Personnel Resources

CONE Phase C/D Management Skills - The skills required to perform program management functions are listed for each of the six WBS level III tasks. These skills shall provide for the following:

- Management - Perform management functions and a management structure to plan, direct and integrate all requirements of the contract SOW through compliance with scheduler, technical, and financial commitments of the contract under the direction of a Program Manager. Financial, program planning, and scheduler implementation and status and formal reviews are included.

- Configuration Management - Will provide for a disciplined and traceable requirements management system that defines, documents, controls, and audits hardware and software configurations and to assure that only authorized change is incorporated.

- Procurement Management - Will provide for the overall establishment and administration of all major and minor subcontracts and also includes materials and parts purchase, supplier evaluation and price analysis vendor quotations.

- Property Management - Perform property accountability, storage, inventory and control functions associated with program unique GFE, test equipment, and material handling and insuring that facilities and plant equipment needed to support the program are available and of the correct type.

- Data Management - Will control preparation, inspection and delivery of contract data.

- Travel - Provide travel services and audit of travel expenses associated with formal and other customer reviews, integration and interface meetings, and vendor and subcontract meetings.

CONE Phase C/D Systems Engineering Skills - The skills required to perform systems engineering functions are listed for each of the six WBS level III tasks. These skills shall provide for the following:

- Mission Requirements & Analysis - Perform evaluation of the overall mission objectives leading to the definition of mission specified and derived requirements which may be functional, performance or operational in nature.

- System Requirements Analysis - Will define an initial hardware and software baseline of engineering requirements to which the system, subsystems, and components will eventually be designed and includes functional analysis, requirements allocation, specification development, trade studies and test requirements generation.

- Systems Design - Will translate the defined system requirements into viable and effective system and subsystem designs.

- Requirements Verification - Provides the what, how, where, and when a specific verification task shall be accomplished. In the case of performance, design and interface requirements, the verification method (inspection, analysis, test, and demonstration) will be specified and tracked to evaluate satisfactory compliance of the requirement.

• Specialty Functions - Will provide unique design specialists to assure that certain engineering design specialties such as reliability, mass properties and EMC are accommodated in the design process.

• Logistics - This effort will provide logistics specialists to perform analyses to define maintenance philosophy, spares policy, personnel/skill/training needs, and many other related activities necessary for operational use of the system needed to achieve definition, optimization, and integration of support resources over the life of the system.

CONE Phase C/D Design Engineering Skills - The skills required to perform design engineering functions are listed for each of the four WBS level III tasks. These skills shall provide for the following:

• Experiment Subsystem - Will provide the total engineering support for the design and analysis of the individual elements of the experiment subsystem.

• Support Subsystems - Will provide the total engineering support for the design and analysis of the individual elements of the support subsystems.

• Ground Support Equipment - Will provide the total engineering support for the design and analysis of the individual elements of the electrical, mechanical, and POCC ground support equipment.

• LN2 Tank Hardware Development - Will provide the total engineering, manufacturing, assembly and test support for the design, analysis, fabrication and test of the LN2 storage tank element of the experiment subsystem.

CONE Phase C/D Software Engineering Skills - The skills required to perform software engineering functions are listed for each of the two WBS level III tasks for flight and ground S/W. These skills shall provide for the following:

• Flight Software - Provide for the development of system level S/W requirements followed by preliminary and detailed design where an architecture and design are developed that meets the capacity and data through put processing requirements with hierarchy down to the lowest S/W level. Design is followed by a structured top-down structured modular code development that also includes checkout of function. The last S/W activity is S/W and H/W integration for test and verification of system level validation.

• Ground Software - Provide for the development of EGSE and POCC level S/W requirements followed by preliminary and detailed design where an architecture and design are developed that meets the capacity and data through put processing requirements with hierarchy down to the lowest S/W level. Design is followed by a structured top-down structured modular code development that also includes checkout of function. The last S/W activity is S/W and H/W integration for test and verification of system level validation.

CONE Phase C/D Fabrication, Assembly, and Test Skills

The skills required to perform fabrication, assembly and testing functions are listed for each of the four WBS level III tasks. These skills shall provide for the following:

• Experiment Subsystem - Will provide the total manufacturing, assembly and test support for the fabrication and subsystem checkout of the experiment subsystem elements.

• Support Subsystems - Will provide the total manufacturing, assembly and test support for the fabrication and subsystem checkout of the support subsystem elements.

• Ground Element - Will provide the total manufacturing, assembly and test support for the fabrication and subelement checkout of the ground support subsystem electrical, mechanical and POCC elements.

• P/L Integration and Test - Provides for the system level integration, checkout and test of the combine flight and ground S/W and H/W elements.

CONE Phase C/D NSTS Integration Skills - The skills required to perform NSTS integration functions are listed for each of the two WBS level III tasks. These skills shall provide for the following:

• Integration Analysis & Documentation - Provide for the establishment of a formal P/L-to-STS integration program where mutually agreeable management, technical, operational, and documentation compatibility are developed with various NASA centers and will form the basic P/L integration definition.

• Flight Hardware Integration - Provide for the establishment of a formal ground processing and flight hardware integration program where mutually agreeable management, technical, operational, and documentation compatibility are developed with various NASA centers and will form the basic hardware integration definition.

CONE Phase C/D Mission Operations Skills - The skills required to perform mission operations functions are listed for each of the three WBS level III tasks. These skills shall provide for the following:

• Ground Operations - P/L carrier integration and checkout at GSFC and STS integration, checkout and servicing at KSC will be provided, as well as post-mission deintegration operations.

• Flight Operations - Will provide for P/L support of the mission at the POCC and at the JSC Mission Support Room, as well as post flight data analysis.

• Training - Provide for STS crew and POCC operator training and development of mission simulations.

CONE Phase C/D Product Assurance Skills - The skills required to perform product assurance functions are shown for each of the three WBS level III tasks. These skills shall provide for the following:

• H/W Product Assurance - Provides for a system based on existing procedures and practices to assure that fabricated and procured hardware items meet contractual and engineering requirements and will include a quality assurance system, change control maintenance, procurement control, GFP processing, material controls, fabrication controls, test plan and procedure review, nondestructive evaluation and inspection, nonconformance and corrective action control, calibration and certification control, packing and shipping controls, equipment log maintenance, failure reporting, parts control, and program quality audits .

• S/W Product Assurance - Provides for a system based on existing procedures and practices that will plan, maintain and implement a S/W Product Assurance Plan that will apply to all design, test, support, and operational flight and ground software and will include S/W reviews, verification and integration, validation and test, monitoring and audit, nonconformance and corrective action, documentation and configuration management, and security access and storage functions.

• Safety - Will provide a the program with necessary personnel and system safety engineering expertise and safety management to assure compliance with required safety practices and requirements documentation and includes STS P/L safety experience, hazard analysis and controls identification and closeout, safety review process and documentation, trade study support, test safety support, S/W safety analysis, ground processing and launch site safety support, mission safety support, accident risk assessment, system safety criteria, system safety checklists, training and certification review, accident investigation and reporting, and fire prevention and protection.

12.4 <u>CONE Phase C/D Facilities Requirements</u>

The facilities environment required to perform the CONE design, development, fabrication, testing and integration has been identified for each level III WBS task and includes office facilities, computer facilities, engineering laboratories, electronic and mechanical manufacturing capability, assembly areas, and test facilities specifically established to support aerospace projects in one location with required tools, technology, and skills requirements. While most of these facilities are common to most contractors in the aerospace community, certain are somewhat specialized in research and development, engineering, manufacturing/assembly, and test capabilities that can accommodate the unique cryogenic needs of CONE where the highest standards of cleanliness, accuracy and quality have to be maintained. These specialized facilities are underlined on Table 12.4-1. A brief description of major facility function is as follows:

• Machine/Model Shop - This capability supports the fabrication and assembly needs of test areas needs with test fixturing and test tooling piece-parts .
• Precision Cleaning Facility - Meeting specific and varied cleaning requirements are accomplished with the support of this area.
• Manufacturing/Fabrication Area - This capability supports the fabrication and assembly of test fixturing and test tooling to support testing needs.
• Clean Rooms - Class 100,000 clean rooms are required for certain in-line acceptance testing and for the overall maintenance of CONE P/L cleanliness during assembly, integration and test.
• Metrology Lab - This lab provides for the periodic calibration and certification of mechanical and electrical test equipment. Measuring equipment are calibrated against traceable primary and secondary standards. All test equipment used must be within its current calibration period.
• Vibration Test Facility - This test facility has the capability to simulate the vibration environment (with margin) of launch and ascent and is used to qualify and/or accept the flight hardware to those environments, when required.
• Acoustic/Modal Survey Test Facility - This test facility has the capability to simulate the acoustic environment (with margin) of launch and ascent and is used to qualify and/or accept the flight hardware to those environments.
• EMI/EMC Test Facility - This test facility has the capability to simulate the RF environment (with margin) of the Orbiter and is used to qualify and/or accept the flight hardware to those environments from both radiated and conducted susceptibility and interference requirements, as needed by the program.
• Cryogenic Test Facility - This facility has the equipment and capability to store, transfer and vent cryogenic fluids (LN2) in support of CONE testing and mission simulations.
• Pneumatic Test Facility - This facility contains the equipment for pneumatic and proof pressure checkout of experiment subsystem elements.
• Thermal Vacuum Chamber Test Facility - Certain tests require a simulation of both the thermal and vacuum space environment. This facility must also be capable of LN2 testing.
• Vacuum Chamber Test Facility - Certain tests require a simulation of the vacuum space environment only. This facility must also be capable of LN2 testing.

• Quality Control Laboratory - This lab contains all the necessary equipment and apparatus to perform the detailed qualitative and quantitative chemical analysis, cleanliness verification, radiographic and penetrant inspections, and failure analysis required to support the CONE program.
• LAD Test Facility - This lab contains the equipment required to verify LAD screen integrity by performing bubble point checks of raw screen material and completed devices.
• Cabling Lab - Wiring harness fabrication, routing checks and electrical connector installation, as well as, pin-to-pin continuity checks are accomplished in this lab.
• Electronic Manufacturing Facility - This facility provides for the custom design and manufacture of electronic hardware, prototype and breadboard fabrication, test fixturing and tooling, and EGSE elements.

Table 12.4-1 Facility Requirements

• General Personnel Areas	Facilities in this class include test team office space, conference rooms and computer terminals needed for the conduct of the effort.
• Computer Facilities	To support the test documentation, conduct and data collection/analysis activities a host of specialized and general purpose computers are required.
• Machine/ Model Shop	This capability supports the fabrication and assembly needs of test areas needs with test fixturing and test tooling piece-parts .
• Precision Cleaning Facility	Meeting specific and varied cleaning requirements are accomplished with the support of this area.
•Manufacturing/ Fabrication Area	This capability supports the fabrication and assembly of flight hardware, as well as, test fixturing and test tooling to support testing needs.
• Clean Rooms	Class 100,000 clean rooms are required for certain in-line acceptance testing and for the overall maintenance of CONE P/L cleanliness during assembly, integration and test.
• Metrology Lab	This lab provides for the periodic calibration and certification of mechanical and electrical test equipment. Measuring equipment are calibrated against traceable primary and secondary standards. All test equipment used must be within its current calibration period.
• Test Control Rooms	Various tests require remote operation of facility equipment and space for CONE unique EGSE.
• Test Data Recording/Storage	Special test instrumentation, as well as CONE H/W experiment and support subsystem data requires recording and storage for later retrieval and data analysis.
• Vibration Test Facility	This test facility has the capability to simulate the vibration environment (with margin) of launch and ascent and is used to qualify and/or accept the flight hardware to those environments, when required.
• Acoustic/ Modal Survey Test Facility	This test facility has the capability to simulate the acoustic environment (with margin) of launch and ascent and is used to qualify and/or accept the flight hardware to those environments. Random noise generators, 1/3 octave spectrum shapers, and power amplifiers provide the electrical excitation for the acoustic shroud (14 ft dia x 15 ft high) noise generator horns. Modal surveys are also conducted in this facility to measure the significant structural modes and modal parameters needed to verify/update the CONE dynamic math models required by GSFC and JSC.

• EMI/EMC Test Facility	This test facility has the capability to simulate the RF environment (with margin) of the Orbiter and is used to qualify and/or accept the flight hardware to those environments from both radiated and conducted susceptibility and interference requirements, as needed by the program. Power provided by the Orbiter is also simulated. This facility consists of two adjoining shielded rooms. A 21 x 30 x 24 ft high, solid, double shielded enclosure provides the main test area with an adjacent 9 x 6 x 7 room for test support equipment placement.
• Cryogenic Test Facility	This facility has the equipment and capability to store, transfer and vent cryogenic fluids (LN2) in support of CONE testing and mission simulations.
• Pneumatic Test Facility	This facility contains the equipment for pneumatic and proof pressure checkout of experiment subsystem elements.
• Thermal Vacuum Chamber Test Facility	Certain tests require a simulation of both the thermal and vacuum space environment. This facility must also be capable of LN2 testing.
• Vacuum Chamber Test Facility	Certain tests require a simulation of the vacuum space environment only. This facility must also be capable of LN2 testing.
• Quality Control Laboratory	This lab contains all the necessary equipment and apparatus to perform the detailed qualitative and quantitative chemical analysis, cleanliness verification, radiographic and penetrant inspections, and failure analysis required to support the CONE program.
• LAD Test Facility	Bubble point checks of screen integrity are accomplished in this facility.
• Cabling Lab	Provides the capability to fabricate and test complex wiring harnesses.
• Electronic Manufacturing Facility	This facility has the capability to manufacture, assemble, and test avionic and electrical units at the box and subsystem level.

12.5 CONE Fabrication and Assembly Overview

A top-level simplified flow chart of the CONE fabrication and subsystem assembly through final system assembly is shown in Figure 12.5-1. The process begins with design approvals after both the PDR and CDR where subcontract and material procurement has to be initiated for critical long lead items. Prior to procurement initiation a Make/Buy Plan has been established for the program. The requirement for a LN2 Storage Tank Test Article (TA) establishes the priority for the design of this item to be complete at the PDR and ready to enter the procurement cycle for fabrication and assembly while the rest of the design is proceeding to the CDR definition. All provisions for TA fabrication, assembly and test have to be incorporated very early into the Manufacturing Plan, Cleanliness & Contamination Control Plan, and into the manufacturing working paper of the Manufacturing Process Plans. Other items may also be identified that require long lead procurement commitment at the PDR.

After the CDR all other procurements are initiated and manufacturing planning is completed to support the subassembly fabrication and experiment and support subsystems assembly. Final CONE assembly is the end of the process which then flows into system level functional, acceptance and performance testing. Parallel MGSE and EGSE fabrication and assembly operations are needed to support various in-line processing and test needs for the various CONE flight elements.

12.6 CONE Phase A/B & C/D Program Schedule

A top level CONE Phase A/B and follow-on C/D program schedule is presented in Figure 12.6-1 and reflects the current view as we understand it for the ongoing continuation of the CONE program which has been delayed by one year. Critical to the ATP of the Phase C/D is the successful completion of the system design Phase B where the experiment and support system requirements are baselined. This design activity ended in mid 1991 with a System Design Review (SDR) and will be followed by a formal Phase C/D RFP and procurement. At this point the design has matured up to a System Design Review (SDR) with two contractors working independently on individual design approaches to the same set of requirements. Most requirements have been thoroughly defined in this phase of the program. Once the Phase C/D starts, a formal PDR with the single Phase C/D contractor proceeding with the favored design will begin the effort. Early in the program (4-5 months after ATP) a formal Software Requirements Review (SRR) will also take place. Twelve to thirteen months after PDR a Critical Design Review (CDR) would be held on the completed finalized design. This design effort assumes that the contractor proceeding with the Phase C/D is one of the contractors that worked with the A/B phase and has a design that is mature enough to meet the required schedule needs for a flight in the middle of 1997. If a contractor other than the two current CONE Phase A/B contractors is selected an additional 9-12 months would have to be added to the schedule. This schedule includes the build of a dedicated LN2 storage tank TA between the PDR and CDR efforts.

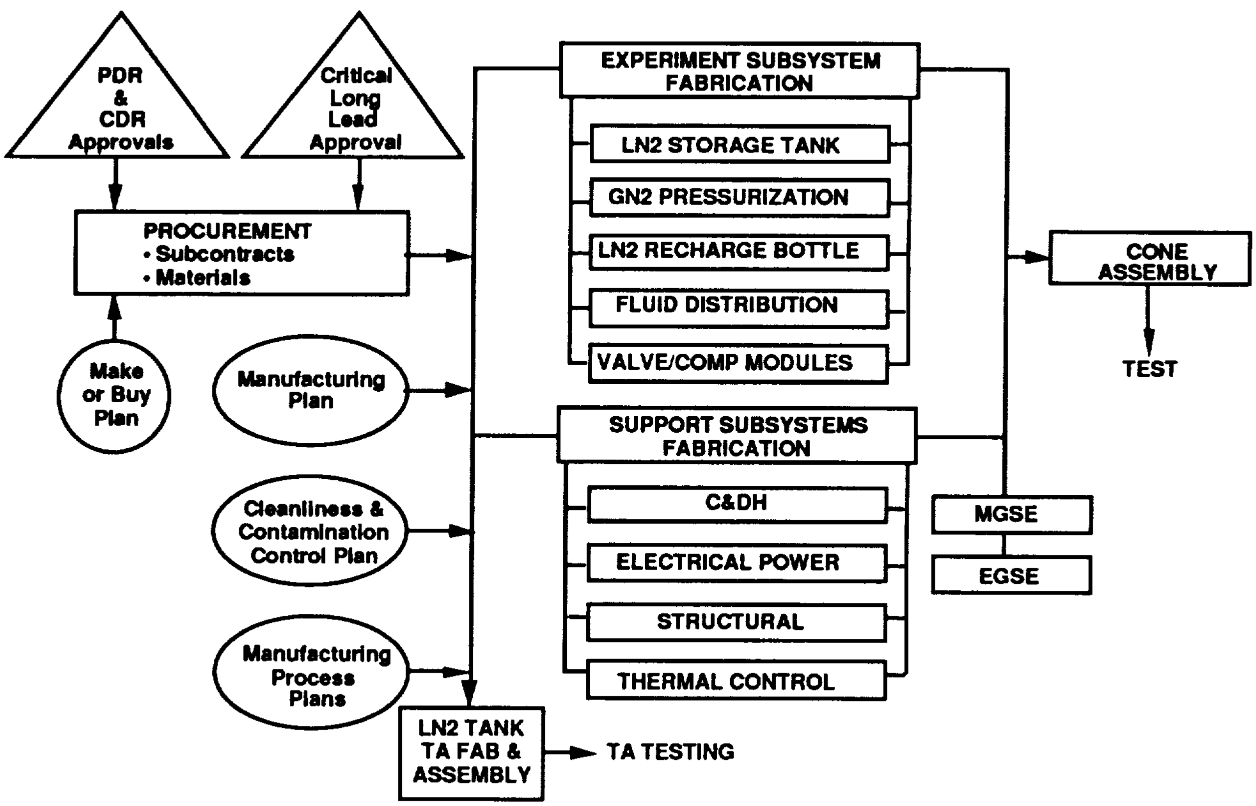


Figure 12.5-1 Fabrication and Subsystem Assembly Flow

The critical milestones to accomplish the phase C/D schedule in close to a four year time frame from ATP to flight is the very early commitment to procure long lead items and to complete the tank development effort. Primarily the long lead items will require new tooling and have long delivery time for basic materials and components. The date to start these procurements is after the PDR where the basic tankage size, shape and configuration has to be fixed so that the LN2 storage tank test article program can begin. Procurement of tank forgings for both the TA and flight tanks must occur simultaneously in order to be cost effective. Final machining of the flight tank will not occur

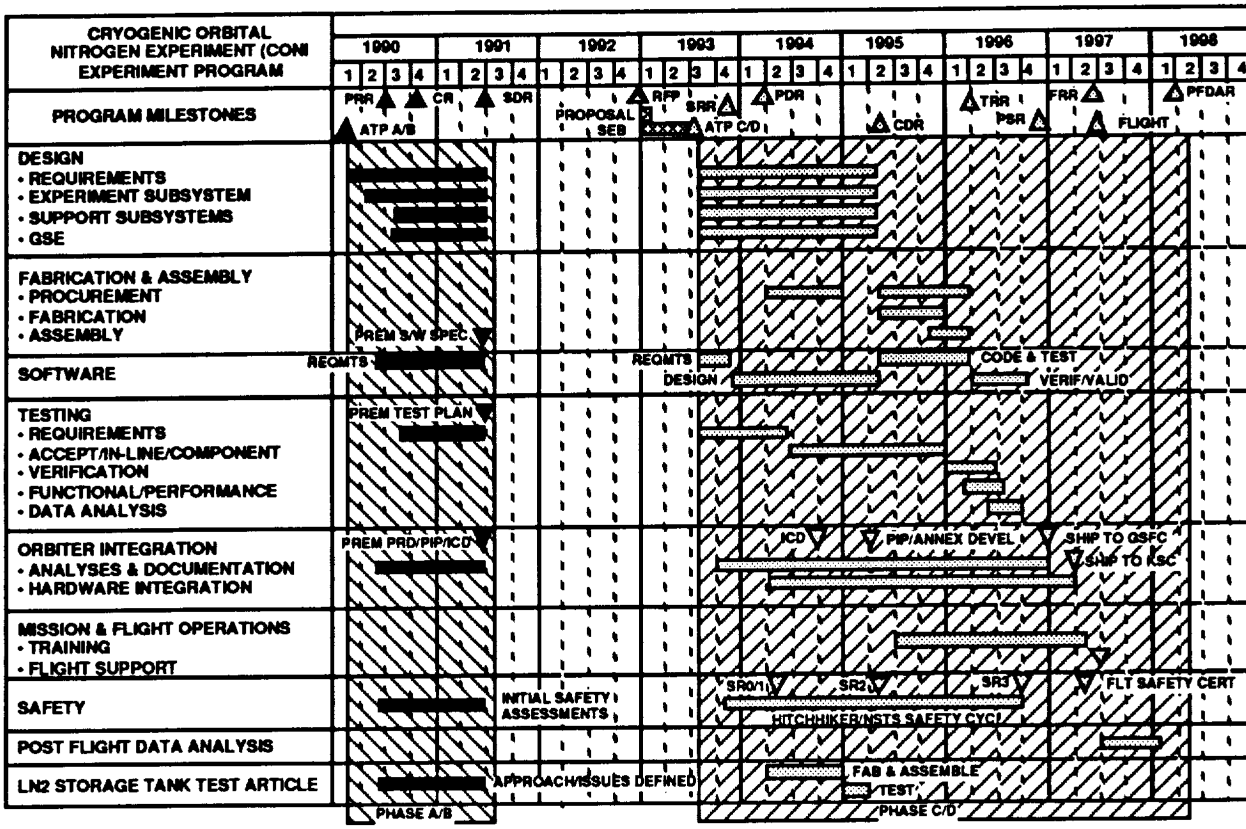


Figure 12.6-1 CONE Program Schedule

until after tank development tests are complete. After PDR commitment to procure support subsystem long lead components and assemblies must be made to meet the schedule and requires the use of a mature C&DH where component interfaces and compatibilities are known and proven . Our proposed C&DH configuration meets these needs.

Equally critical to long lead procurement is the establishment of a supporting cryogenic technology development program and component level qualification that will mitigate design risk by the CDR for certain component areas. Some of the component development is critical for system level characterizations. Such a component is the mixer, tank liquid level sensor, and certain other component issues which will be integrated into the LN2 storage tank TA for tank level qualification. Prior to this time, the pump will have been qualified to operate with LN2 and the operating characteristics will have been determined at the component level. As an example the development of the mixer pump has to proceed to this point [independent of TVS/CHX development] before the combined pressure control features of both can be meshed.

After CDR an 18 month manufacturing, fabrication, assembly, integration and test activity of the experiment and support subsystems takes place. A six-seven month carrier integration occurs at GSFC (for the baselined HH-M approach) while the launch operations and STS integration takes place at Kennedy Space Center.

13.0 CONCLUSIONS AND RECOMMENDATIONS

This seventeen month CONE design study has demonstrated the feasibility of a highly focused, NSTS launched in-bay cryogenic payload that would concentrate on providing data relating primarily to the storage and outflow of subcritically stored cryogens (using LN2 as the test fluid). The experiment subsystem was configured to address required technical objectives and design goals for the execution of the developed experiment set consisting of both demonstration and experiment categories of test. We selected the Hitchhiker-M as the most cost effective carrier for attaching CONE to the Orbiter while providing the best interface accommodations to required command, control, data and power services.

The most significant factor in the development of the CONE configuration and the resulting mission and experiment set definition was the limited duration of the Orbiter mission and the desire to accomplish all technical objectives within a standard seven day flight. This goal was met by an experiment timeline and experimental subsystem dominated by a LN2 storage tank configuration and size that traced back to the defined requirements and constraints for all categories of test.

While not formally addressing the incorporation of fluid transfer, we believe that such an accommodation can be easily added to the existing CONE approach without impacting the mission length. Two or three transfers to a receiver tank can be accomplished with the existing LN2 consumables budget which is currently being outflowed to space.

13.1 Program Issues

CONE top issues and major areas which drive the design, cost and science fidelity of the program are discussed below. Normally a large number of these issues would have been resolved prior to the completion of the program. This was not possible with the CONE program due to the lack of formal interchange with JCS, KSC, and GSFC, as well as the lack of adequately assessing the planned incorporation of fluid transfer and receiver tank filling into the approach. All of these issues remain open and should be carried over into any follow-on efforts.

Orbiter Assessments - The major mission issue concerns manifesting the payload onto a Shuttle flight that will accommodate CONE needs for venting and several Orbiter attitude and thrusting requirements for fluid positioning and settling.

Informal TIMs at JSC, KSC and GSFC have taken place. Concerns were addressed and a better understanding of CONE unique constraints on both the Orbiter, carrier and ground processing were discussed without any commitment on the part of any of the listed centers.

Many of these negotiated needs will become a part of the normal working group activities of the NSTS integration and PIP/Annex development process which GSFC will lead.

Venting - In order to be cost effective, a convincing approach has to be developed, analyzed, and presented that provides for safe venting of the CONE GN2/LN2 effluents during all nominal and contingency mission phases. This includes nominal TVS and emergency venting within the cargo bay with the payload bay doors closed and to space with the doors open when the CONE is active and performing tests that expel fluid from the system. Availability, use, location, and cost of an Orbiter vent system to accommodate some or all of these needs requires further assessment and coordination with JSC. Similarity to SHOOT as a precursor has been used for initial venting approach development and should be used in follow-on efforts where applicable.

Crew Involvement - Crew involvement with CONE has been minimized where possible. Issuing commands from the standard switch panel is a minor effort, albeit one that must be coordinated time wise. Maneuvering and reorienting the Shuttle, as well as firing of thrusters creates a more involved timeline. Use of crew non-sleep periods is the dominating criteria in the development of the length of each test in the experiment timeline. The amount of data that the crew may require for monitoring has not been defined. Our baseline approach does not provide such a data stream that can be recognized by the GPC.

Ground Data Monitoring and System Power Up - After the CONE has been serviced with LN2, periodic monitoring will have to be accomplished to status important P/L data so that nominal performance can be verified and to commit to configuring for launch. The most straight forward (and also probably the most costly) technique to meeting this need is the T-0 umbilical approach. At any time the P/L can be powered up from ground power and the system can be statused. Inadvertent commanding issues have to be addressed for this option. Also a T-0 umbilical is not an optional service per the HH CARS. We have baselined a monitoring approach that provides for periodic HH-M power-up from the SSP and then having KSC provide CONE data routed to the KSC EGSE location or to the LPS P/L console in the LCC by a data strip out from either the PDI or the GPC. KSC desires will greatly influence the final approach selected.

Testing/CONE Certification - Certain testing contributes to the data package that supports payload certification for flight on the Orbiter. Since no formal interchange occurred during this phase with GSFC, JSC and KSC a conservative full-up testing approach has been baselined with the qualification that several areas need to be revisited as so as formal agreements are implemented with these centers. A brief discussion of each follows:

- LN2 Storage Tank TA - The need for a TA is driven by the success in formulating a protoflight approach for the tank based on large design margins and a comprehensive test program that provides enough data to support such an approach. Other development, fabrication and assembly needs should also be considered, as well as schedule impacts of a TA and cost implications to the program.

- Modal Survey Need - How some of the structural design and testing requirements with regard to dynamic characterization for a payload such as CONE that is spread out over various mounting plates and attachment structures remains an open issue that will require coordination with the GSFC HH-M Project Office. Designing the system for as high a fundamental frequency as possible is a goal that will have to be meshed with the mission and experimental needs of the program.

- Deferral of Testing - Certain component and in-line testing can be deferred and accomplished at the system level when enough confidence exists that such postponement will not compromise the system and add unacceptable cost, schedule or system performance risk to the program. Much uncertainty in component characterization and use with cryogens and operation in the space environment will tend to a more conservative and therefore a more costly approach.

- Test/Analytical Mix - Analysis can play an important part in the CONE verification program to support test effort , as well as demonstrating sufficient margin so that testing may be eliminated. Previous usage, heritage and design confidence in the listed areas will all contribute to achieving the proper mix of test and verification analysis.

- Design/Mission Issue Resolution - Various open design issues remain that drive test requirements on how the system will be tested. Until these are resolved and a more definitized baseline can be established in the follow-on phase C/D, best engineering judgement was used to approach the verification process and how the SDR baselined design would be tested.

Carrier - Multiple payloads on the Hitchhiker can present a problem in having the amount of power available when needed. Other users also can inhibit the Shuttle reorientation from occurring when requested by CONE. Currently CONE takes up a large portion of the shape and services of the HH-M. Other payloads can be accommodated which is a follow-on integration item that will have to be worked between GSFC and LeRC.

Weight and cg limitations imposed by GSFC will not be specified by GSFC until the payload agreements are signed. Our approach for the attachment of the LN2 storage tank uses unique structure spanning two standard attachment locations. GSFC review and concurrence with this approach has not occurred.

Early assessment of CONE requirements resulted in a size that could only be accommodate by a MPESS type of carrier. Details of HH-M vs full-up MPESS (1/4 bay P/L) were assessed with the HH-M being favored as the most cost effective. GSFC involvement has both plus and minus considerations that still have been factored into the selection process. The first GSFC interchange has occurred. Meeting 35-50 Hz frequency and CG constraints and the amount and type of testing for payload certification are current open issues.

Unresolved Design Drivers - At the start of the requirements definition and the associated conceptual and preliminary design development it became evident that several items would become the top issues and design drivers for CONE. They are discussed briefly below.

- Scaling of the experimental design to full scale systems for STV applicability has been one of the items that has been greatly worked in developing the CONE approach and LN2 tank sizing. A compromise of experiment size (and resulting weight) had to be made to achieve reasonable test time that is a severe constraint for accomplishing desired testing.

- Paramount in developing the CONE approach is to insure that a safe concept is provided that meets all of the specified safety requirements. Initial informal JSC/KSC safety meetings took place and the approaches presented were favorably received. However, no concurrence was obtained.

- LN2 loading and contingency management for Orbiter abort considerations was incorporated into our operations approach.

- In addition to nominal CONE venting up to 4.1 kg/hr (9 lb/hr), tank outflow up to 227 kg/hr (500 lb/hr) also has to be accommodated on-orbit after the P/L bay doors have been opened and the CONE orbital mission has been approved to proceed. Shuttle mission abort venting into the bay averages 13.6 kg/hr (30 lb/hr).

- Since most of the CONE flight element has the potential of being converted into a Cryogen Transfer Experiment, the initial design has to consider the reflight potential of the hardware and the turnaround issues associated with a potential second mission.

- A fluid transfer potential imposes an additional constraint in that growth requirements and technical objectives that transfer may impose upon CONE has to be incorporated up-front in the CONE concept development. The full impact of fluid transfer on CONE remains to be assessed.

CONE Concept Review Action Item Status - During and after the Concept Review, held on September 18-19, 1990, a series of comments, critiques, questions and concerns were collected which formed the basis for the updates to the concept so that preliminary design could begin. A first set of action items was compiled as a result of minutes and notes taken during the CR. A second set was generated by NASA LeRC as a result of post-CR review of presentation information.

All dispositions and answers to these items have been coordinated with NASA LeRC over the period of performance of the Task V.4 effort. A summary of the three items that are still open is provided below:

• Item MM-1: A GSFC response is needed to resolve issues of the CG location. A verbal OK was given by GSFC to keep the cg between the HH-M sill trunnion locations, which we have done. A review by GSFC of the CONE configuration is still needed.

Response: Due the lack of an official agreement for GSFC support no review or critique of our CONE/HH-M approach has been accomplished. This item will be deferred to the CONE C/D.

• Item MM-21: Use of the in-bay SAMS package requires active cooling. How will this be accommodated?

Response: An existing accelerometer package that can be used by the CONE program is desired so that this data can be used to better understand the CONE science objectives. Certain information regarding SAMS and other potential accelerometer options is deferred to the phase C/D.

• Item MM-43: We should request a structural math model of the HH-M from GSFC.

Response: Again, due to the lack of an official agreement with GSFC the obtaining of needed models has not been accomplished. Also a downscoping of Subtask V.4 effort in these analytical support areas makes the obtaining of these models a phase C/D item.

13.2 Conclusions

Over the years, a three step approach to cryogenic fluid management technologies has been defined starting with individual component and hardware development, progressing to subsystem element ground based testing and finally to in-space experimentation. All result in the establishment of a cryo data base and to the development of refined analytical models which make use of the available data for validation and correlation purposes. CONE is the needed first precursor experiment to implement a cost effect, subscale on-orbit test approach focused on the near term needs of the space community.

Cryogenic fluid management technologies have been identified and examined throughout various studies by both NASA and contractors. Planning for a comprehensive orbital test of these key technologies was begun in 1978 by NASA LeRC and Martin Marietta with the Cryogenic Fluid Management Experiment (CFME). These studies progressed to include fluid transfer with the Cryogenic Fluid Management Facility (CFMF). With the Space Shuttle Challenger accident, however, safety considerations have made the flying of liquid hydrogen on the Shuttle extremely difficult. As a result, alternate approaches have been developed resulting most recently in the COLD-SAT and CONE programs. We have been involved with the evaluation of various experimental options and their ability to satisfy both primary (enabling) and secondary (enhancing) experiment objectives. Other options for orbital testing that have been examined include Space Shuttle attached payloads, Space Shuttle deployable payloads, Space Station attached payloads, small satellite experiment ELV launched packages and Centaur upper stage experiments.

During this time, the prime objective has always been the same, namely, the development of a cryogenic fluid management database and experimentally verified analytical models which characterize the thermophysical processes associated with the on-orbit storage, transfer, and resupply of subcritical cryogenic liquids. Various future missions have been identified that require or would derive benefit from the development of this technology. Cryogenic technology has consistently placed high on priority lists and often is the number one item. Methods for obtaining experimental data to satisfy these technology needs have taken various directions over the years with the current emphasis being precursor CONE demonstrations and experiments using LN2 before commitment to more extensive LH2 experiments. The direction of these studies has never resulted in the maturation of efforts into hardware and flight programs. A systematic approach has been specified which can evolve from component development to process and subsystem performance assessments using a combination of ground testing and subscale on-orbit demonstrations that provide technology return, cost effectiveness, risk mitigation, and timeliness.

Regardless of the specific on-orbit fluid management experiment concept, it is only of value if the resulting data and observations can be applied to the design of a full-size system. In some cases, it will be possible to directly apply the test results. When the fluid properties and/or the experiment geometry differ significantly from the full scale system, then scaling methods using dimensionless parameters that characterize the key physical processes must be used. Therefore, scaling will be an important factor in the assessment of the various experiment concepts.

It is time to proceed out of the study phase and into a commitment where hardware can be built, flown and data can be collected. By attempting to define and develop the "right" experiment to fly, the NASA decision makers have been recently overwhelmed by a $300M COLD-SAT approach that could not be afforded. Over the years a decision could never be made to commit to the continuance of any of the LH2 payloads suggested for the Orbiter. The best and most cost effective near term in-space flight experiment is currently being worked with NASA-LeRC in the form of CONE. It is highly focused, uses a non reactive cryogen (LN2), flies as a Hitchhiker-M class of experiment and supports both Space Station Freedom and Space Transportation Vehicle cryogenic technology needs, as well as other generic needs of space depots, tankers, and other related systems. While cryogen transfer and resupply to a user tank is currently not a part of the technical objectives, we believe that such a requirement could be accommodated into CONE and accomplished in a single Orbiter mission.

The CONE conceptual design study has demonstrated the feasibility of a cryogenic LN_2 experiment on the Shuttle that would provide an initial data base relating to the thermophysics of subcritical cryofluids in low-g environment in certain key areas of tank storage and outflow. The resulting information will provide enabling and enhancing technological information to support the design and operation of future systems using such fluids.

A single string approach to reliability was chosen to reduce cost. The length of the CONE mission increases the reliability of the system without the need for redundancy. Any risk associated with the single string approach does not involve system safety, only the possibility of having to refly the experiment at a later time with modified hardware.

Decisions are being made today on various programs that greatly impact system configuration and operational effectiveness based on not having to advance the state of the art in cryogenics. Commitments have to be made now so that needed technologies will be sufficiently be developed for the ambitious programs of the future. By not realizing these critical technology advancements we relegate these visions to the realm of unachievable undertakings.

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16. Abstract Subcritical cryogenic fluid management (CFM) has long been recognized as an enabling technology for future space missions. Subcritical liquid storage and supply are two of five CFM technology areas that need to be investigated in the low gravity on-orbit environment. The Cryogenic Orbital Nitrogen Experiment (CONE) is a LN2 cryogenic storage and supply system demonstration placed in orbit by the National Space Transportation System (NSTS) Orbiter and operated as an in-bay payload. In-space demonstration of CFM using LN2 with a few well defined areas of focus would provide the confidence level required to implement subcritical cryogen use and is the first step towards the more far reaching issue of cryogen transfer and tankage resupply. A conceptual approach for CONE has been developed by Martin Marietta and an overview of the CONE program is described which includes the following: (1) a definition of the background and scope of the technology objectives being investigated, (2) a description of the payload design and operation, major features and rationale for the experiments being conducted, and (3) the justification for CONE relating to potential near-term benefits and risk mitigation for future systems. Data and criteria will be provided to correlate in-space performance with analytical and numerical modeling of cryogenic fluid management systems, as well as demonstration data for the mitigation of design risk. CONE results are tailored to provide increased confidence for the use of subcritical cryogen storage and supply for various future applications including Space Station Freedom growth options and space propellant storage. The CONE Experiment Set provides both experimental and demonstration data for space missions, providing fluid management technology in the following areas of emphasis: 1) cryogenic liquid storage, 2) liquid nitrogen supply, 3) pressurant bottle recharge, 4) active pressure control, and 5) liquid acquisition device performance (expulsion efficiency). Active pressure control is the highest priority of scientific investigation and is the only experiment category of test. All others are demonstrations where the technical objectives tend to be less scientific in nature.

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